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Nonlinear system identification and control using state transition algorithm

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ABSTRACT

By transforming identification and control for nonlinear system into optimization problems, a novel optimization method named state transition algorithm (STA) is introduced to solve the problems. In the proposed STA, a solution to a optimization problem is considered as a state, and the updating of a solution equates to a state transition, which makes it easy to understand and convenient to implement. First, the STA is applied to identify the optimal parameters of the estimated system with previously known structure. With the accurate estimated model, an off-line PID controller is then designed optimally by using the STA as well. Experimental results have demonstrated the validity of the methodology, and comparisons to STA with other optimization algorithms have testified that STA is a promising alternative method for system identification and control due to its stronger search ability, faster convergence rate and more stable performance.

1. Introduction

The identification and control of nonlinear system have been widely studied in recent years [1–4]. Before the design of a controller, it is necessary to achieve system identification. In general, the process of system identification can be decomposed into two steps: the selection of an appropriate identification model (system structure) and an estimation of the model's parameters, of which, the parameter estimation plays a relatively more important role since a specific class of models that can best describe the real system can usually be derived by mechanism analysis of industrial processes [5].

As for techniques of parameter estimation, approaches such as least-squares method, instrumental variable method, correlative function method, and maximum-likelihood method are widely used [6,7]. Especially for the least-squares method, it has been successfully utilized to identify the parameters in static and dynamic systems [8]. However, most of these techniques have some fundamental issues, including their dependence on unrealistic assumptions such as unimodal performance and differentiability of the performance function, and they are easily getting trapped into local optimum, because these methods are in essence local search techniques based on gradient. For example, the least-squares method is only suitable for the model structure possessing some linear property. Once the model structure exhibits nonlinear performance, this approach often fails in finding a global optimum and becomes ineffective [5–7,9].

Fortunately, the modern intelligent optimization algorithms, such as genetic algorithm (GA) [10,11], particle swarm optimization (PSO) [12,13], are global search techniques based not on gradient, and they have been successfully applied in various optimization problems even with multimodal property. As a matter of fact, some intelligent optimization algorithms have been utilized in the field of nonlinear system identification and control. In [14], estimation of bar parameters with

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binary-coded genetic algorithm was studied, and it was verified that the GAs can produce better results than most deterministic methods. Genetic algorithm based parameter identification of a hysteretic brushless exciter model was proposed in [15]. In [7,16], real-coded genetic algorithms were applied for nonlinear system identification and controller tuning, and the simulation examples demonstrated the effectiveness of the GA based approaches. Then, in [5,6,9], parameter estimation and control of nonlinear system based on adaptive particle swarm optimization were presented, and examples confirmed the validity of the method. Further more, in [17], identification of Jiles–Atherton model parameters using particle swarm optimization, and in [18], parameters identification for PEM fuel-cell mechanism model based on effective informed adaptive particle swarm optimization were put forwarded subsequently. All of these indicate that intelligent optimization techniques are alternatives for traditional methods including gradient descent, quasi-Newton, and Nelder–Mead's simplex methods.

Although GA and PSO are alternative approaches for the problem, they always encounter premature convergence and their convergence rates are not so satisfactory when dealing with some complex or multimodal functions [19,20]. State transition algorithm (STA) is a novel optimization method based on the concept of state and state transition recently, which originates from the thought of state space representation and space transformation [21,22]. In STA, four special transformation operators are designed, and they represent different search functions in space, which makes STA easy to understand and convenient to implement. For continuous function optimization problems, STA has exhibited comparable search ability compared with other intelligent optimization algorithms [23,24].

In this paper, the STA is firstly introduced to identify the optimal parameters of nonlinear system. Then, we will discuss the off-line PID controller design by adopting STA according to the estimated model. The PID control is popular due to its ease of use, good stability and simple realization. The key issue for PID controller design is the accurate and efficient tuning of PID control gains: proportional gain K_p, integral gain K_i and derivative gain K_d. For adjusting PID controller parameters efficiently, many methods were proposed. The Ziegler–Nichols method is an experimental one that is widely used; however, this method needs certain prior knowledge on a plant model [25]. Once tuning the controller by Ziegler–Nichols method, a good but not optimum system response will be gained. On the other hand, many artificial intelligence techniques such as neural networks, fuzzy systems and neural-fuzzy logic have been widely applied to the appropriate tuning of PID controller gains [26]. Besides these methods, modern intelligent optimization algorithms, such as GA and PSO, have also received much attention, and they are used to find the optimal parameters of PID controller [5,7,16].

The goal of this paper is to introduce a novel method STA for both parameter estimation and control of nonlinear systems. In order to evaluate the performance of the STA, experiments are carried out to testify the validity of the proposed methodology, the results of which have confirmed that STA is an efficient method. Compared with other intelligent optimization algorithms, the simulation examples have demonstrated that the STA has superior features in terms of search ability, convergence rate and stability.

2. Problems description

To transform a specified problem into the standard form of optimization problem is called optimization modeling, which is the basis for parameter identification and system control. The standard optimization problems should consist of objective function and decision variables, while optimization algorithms are used to find a global optimal solution to the objective function restricted to some additional constraints.

2.1. Identification of nonlinear system

In this paper, the following class of discrete nonlinear systems described by the state space model is considered:

$$\begin{aligned} x(k+1) &= f(k, x(k), u(k), P_1) \\ y(k) &= h(k, x(k), u(k), P_2), \end{aligned} \tag{1}$$

where, $x \in \Re^n$ is the state vector, $u \in \Re$ is the input, $y \in \Re$ is the output, P_1 and P_2 are unknown parameter vectors that will be identified, and $f(\cdot)$ and $h(\cdot)$ are nonlinear functions. Without loss of generality, let $\theta = [\theta_1, \theta_2, \ldots, \theta_n]$ be a rearranging vector containing all parameters in P_1 and P_2 where n represents the total number of unknown system parameters. Furthermore, the estimated system model can be described as:

$$\begin{aligned} \hat{x}(k+1) &= f(k, \hat{x}(k), u(k), \hat{P_1}) \\ \hat{y}(k) &= h(k, \hat{x}(k), u(k), \hat{P_2}), \end{aligned} \tag{2}$$

where, $\hat{x} \in \Re^n$ and $\hat{y} \in \Re$ denote the state vector and the output of the model, $\hat{P_1}$ and $\hat{P_2}$ are the estimated parameter vectors, respectively. Accordingly, let $\hat{\theta} = [\hat{\theta}_1, \hat{\theta}_2, \ldots, \hat{\theta}_n]$ be the estimated rearranging vector.

The basic thought of system identification is to compare the real system responses with the estimated system responses. Moreover, to accurately estimate the $\hat{\theta}$, some assumptions on the nonlinear systems are required:

(1) The system output must be available for measurement.
(2) System parameters must be connected with the system output.