Nonlinear model identification of an experimental ball-and-tube system using a genetic programming approach

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ABSTRACT

Most processes in industry are characterized by nonlinear and time-varying behavior. The identification of mathematical models typically nonlinear systems is vital in many fields of engineering. The developed mathematical models can be used to study the behavior of the underlying system as well as for supervision, fault detection, prediction, estimation of unmeasurable variables, optimization and model-based control purposes. A variety of system identification techniques are applied to the modeling of process dynamics. Recently, the identification of nonlinear systems by genetic programming (GP) approaches has been successfully applied in many applications. GP is a paradigm of evolutionary computation field based on a structure description method that applies the principles of natural evolution to optimization problems and its nature is a generalized hierarchy computer program description. GP adopts a tree structure code to describe an identification problem. Unlike the traditional approximation methods where the structure of an approximate model is fixed, the structure of the GP tree itself is modified and optimized and, thus, there is a possibility that GP trees could be more appropriate or accurate approximate models. This paper focuses the GP method for structure selection in a system identification applications. The proposed GP method combines different techniques for tuning of crossover and mutation probabilities with an orthogonal least-squares (OLS) algorithm to estimate the contribution of the branches of the tree to the accuracy of the discrete polynomial Nonlinear AutoRegressive with eXogenous inputs (NARX) model. The nonlinear system identification procedure, based on a NARX representation and GP, is applied to empirical case study of an experimental ball-and-tube system. The results demonstrate that the GP with OLS is a promising technique for NARX modeling.

1. Introduction

Developing models from observed data, or function learning, is a fundamental problem in engineering systems. Many engineering approaches such as model-based control systems require accurate process models. However, the majority of physical systems contain complex nonlinear relations, especially in case of hard nonlinearities and chaotic behavior, which are difficult to model with conventional techniques.

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System identification is the procedure of constructing a mathematical model from input–output data for a dynamic system under testing and characterizing the system behaviors. The identification of dynamic nonlinear systems, which pose problems and require solutions distinct from their linear counterparts, is a hard task as demonstrated by the effort devoted by researchers in the last decades. Several techniques have been proposed for identification of nonlinear systems [1–4]. The most widespread identification techniques proposed in literature including bilinear models [4], Wiener–Hammerstein block-oriented models [5], Volterra series [6], Nonlinear AutoRegressive Moving Average eXogenous (NARMAX) models [7], artificial neural networks [8], fuzzy models [9], neuro-fuzzy models [10], principal component analysis [11], evolutionary algorithms [12,13], and others [1–4].

In recent years, genetic programming (GP) [14–22], a member of the evolutionary computation field, has been applied to fault detection, modeling and identification of nonlinear systems. GP is a stochastic process for automatically generating computer programs and was introduced by John Koza [23], based on the idea of genetic algorithms. An advantage of GP is that it can evolve a solution automatically from the training data, and does not require an assumption regarding the mathematical model of the structure or the size of the decision tree-based solution.

1.1. Goals

This paper investigates the design of a GP based on different tuning approaches of crossover and mutation probabilities and the orthogonal least-squares (OLS) algorithm [24] to estimate the contribution of the branches of the tree to the accuracy of the discrete polynomial Nonlinear AutoRegressive with eXogenous inputs (NARX) model.

The effect of different tuning approaches of crossover and mutation probabilities is compared and that provides interesting insight into GP design combined with OLS algorithm to identify NARX models. To illustrate the power of the proposed GP methodology in NARX identification, an experimental ball-and-tube system [25] has been considered.

The procedure identification using GP based on OLS for NARX nonlinear identification validated in this paper was inspired in [26]. Therefore, there are differences between the results presented in this paper and in paper [26]. The paper [26] proposes a GP based on OLS for NARX nonlinear identification. On the other hand, the contributions of this paper are: (i) evaluation of seven GP approaches to tune the mutation and crossover probabilities, (ii) performance index for identification results based on multiple correlation index, and (iii) evaluation of practical case of an experimental ball-and-tube system.

1.2. Organization

The remainder of this paper is organized as follows. In Section 2, the fundamentals of system identification are presented. The theoretical background of GP method is introduced in Section 3. Description of ball-and-tube system and the identification results are both commented in Section 4. Finally, the conclusion and further research are discussed in Section 5.

2. System identification

System identification is concerned with choosing mathematical models to characterize the input–output behaviors of an unknown system using observed data of process. In terms of system identification, linear system identification is a field that has evolved considerably during the last decades [27,28]. The linear mathematical model is useful if the underlying physical process exhibits qualitatively similar dynamic behavior to the linear model in the operating point of interest. However, it is often difficult to represent the behavior of the system over its full range of operation using linear mathematical models.

For these reasons, there is much current research interest in models for nonlinear identification. Nonlinear identification techniques may provide a solution to this problem. Meanwhile, it is important to note that several practical examples of nonlinear dynamic behavior have been reported in the recent engineering literature [1–13,29–32].

This paper investigates a GP method combined with OLS algorithm to NARX modeling. In this context, the procedure for identification adopted is summarized by the following steps:

 (i) design an experiment to obtain the process input/output data sets pertinent to the model application;
 (ii) examine the quality of measured data, removing trends and outliers;
(iii) construct a set of candidate models based on information from the experimental data sets (or simulation data sets). This step is the model structure identification;
(iv) select a particular model from the set of candidate models and estimate the model parameter values using the experimental data sets (or simulation data sets).
 (v) evaluate how good the model is using a performance criterion;
(vi) if a satisfactory model is still not obtained in step (v) then repeat the procedure either for step (i) or step (iii), depending on the problem.