GA-optimized neuro-fuzzy approach for nonlinear system modeling

Behnam Mehrkian [1], Arash Bahar [1], Ali Chaibakhsh [2]

[1] Department of Civil Engineering, University of Guilan, Rasht, Guilan, Iran
[2] Department of Mechanical Engineering, University of Guilan, Rasht, Guilan, Iran
behnam_mkian@webmail.guilan.ac.ir
bahar@guilan.ac.ir
chaibakhsh@guilan.ac.ir

Abstract

In order to characterize the behavior of nonlinear dynamic systems many different approaches have been proposed in recent years. One of the best black-box models employed to deal with system nonlinearities is the combination of artificial neural network (ANN) and fuzzy logic system (FLS), which is known as neuro-fuzzy system. However, the gradient-based nature of this combination causes some deficiencies. Therefore, in this paper, an optimization approach which utilizes genetic algorithm (GA) as a derivative-free optimizer is proposed for both designing the structure of neuro-fuzzy model and assessing the model parameters. The whole proposed approach is applied to approximate: first, a nonlinear plant; next, nonlinear dynamic behavior of magneto-rheological (MR) damper, which is widely used in semi-active control of structures and its identification is significantly difficult due to inherent hysteretic and highly nonlinear behavior of the device. Comparisons between the responses of the models and the reference data show high accuracy and feasibility of the proposed approach.

Keywords: fuzzy, genetic algorithm, backpropagation learning, MR damper, earthquake record.

1. INTRODUCTION

Soft computing platform emerged as a simple but effective technique for describing wide variety of plant behaviors with and without a priori knowledge about the plants. Fuzzy logic system (FLS) is an intelligent tool imitating the logical thinking of human and then is capable of approximating any continuous function. However, there is no systematic method to design and examine the number of rules, input space partitioning and membership functions (MFs). Meanwhile, artificial neural network (ANN), as a derivative-based approach mimics the biological information processing mechanisms. This technique modifies its behavior in response to the environment, and is ideal in case that the expected mapping algorithm is un-known and the tolerance to faulty input information is required. But because of its derivative nature, some deficiencies may occur. The other exploitation for adopting and optimizing fuzzy systems is employing derivative-free optimization methods such as genetic algorithm (GA) [1, 2], simulated annealing (SA) [3], the random optimization method [4], and so on. Although the randomness and stochastic nature of these algorithms are advantages, some unique features of derivative-based algorithms are not employed. In this paper, neural network capabilities and genetic algorithm attributes are tuned to fuzzy structure to predict the behavior of some nonlinear plants in a high level of accuracy. The paper is organized as follows: in section two, Takagi–Sugeno (T-S) fuzzy model and its learning paradigm are reviewed; next, backpropagation (BP) learning as a well-known part of the learning procedure is studied in section three; how genetic algorithm (GA) is employed in this paper is introduced in section four; proposed approach is explained in section five; finally, in order to evaluate the proposed approach, application examples (AE) are brought in section six.

2. TAKAGI–SUGENO FUZZY MODEL

The Takagi–Sugeno (T–S) fuzzy model is a system described by fuzzy IF–THEN rules which can give local linear representation of the nonlinear system by decomposing the whole input space into several partial fuzzy spaces and representing each output space with a linear equation. Such a model is capable of approximating a wide class of nonlinear systems. For the reason that it employs linear model in the consequent part, conventional linear system theory can be applied for the system analysis and synthesis accordingly. And hence, the T–S fuzzy models are becoming powerful engineering tools for modeling and control of complex dynamic systems [5]. To construct a fuzzy model choosing a strategy to partition the input space is needed. If we use the grid partitioning strategy, which is the commonest method, then the structure of fuzzy model could be expressed by the following fuzzy IF–THEN rules that, is shown in Figure 1.

Rule i: $IF\ x_1\ is\ A_i^1\ and \cdots and\ x_{N_I}\ is\ A_i^{N_I},\ THEN\ y_i = a_i^0 + a_i^1 + \cdots + a_i^{N_I} x_{N_I}$, (1)