

Chapter 49

Nonlinear System Identification of Smart Buildings

Soroush Mohammadzadeh
University of Oklahoma, USA

Yeesock Kim
Worcester Polytechnic Institute (WPI), USA

ABSTRACT

In this book chapter, a system identification method for modeling nonlinear behavior of smart buildings is discussed that has a significantly low computation time. To reduce the size of the training data used for the adaptive neuro-fuzzy inference system (ANFIS), principal component analysis (PCA) is used, i.e., PCA-based adaptive neuro-fuzzy inference system: PANFIS. The PANFIS model is evaluated on a seismically excited three-story building equipped with a magnetorheological (MR) damper. The PANFIS model is trained using an artificial earthquake that contains a variety of characteristics of earthquakes. The trained PANFIS model is tested using four different earthquakes. It was demonstrated that the proposed PANFIS model is effective in modeling nonlinear behavior of a smart building with significant reduction in computational loads.

INTRODUCTION

The use of smart control devices such as magnetorheological (MR), electrorheological (ER) damper, variable friction devices, and etc. promises a high potential of increase in the reliability of buildings under destructive environmental forces ranging from strong winds to earthquakes. These benefits come with the challenge of modeling the structure integrated with the nonlinear smart dampers. The integration of the building with smart dampers may introduce nonlinearities despite the building behaving linearly. (Kim *et al.* 2009). Thus, it is critically important to develop an effective model such that the nonlinear behavior of a smart building is captured. In this chapter, a method is studied that efficiently (in terms of computational load) identifies nonlinear behavior of seismically excited buildings equipped with smart dampers.

DOI: 10.4018/978-1-5225-1908-9.ch049

An essential part of modeling smart structures is system identification (SI) that develops a numerical model based on experimental data collected from the smart structure. The SI models are used to reliably estimate the complex behavior of the smart structure subject to a variety of dynamic loading scenarios using the inputs (in this case earthquake and control force) and outputs (in this case, displacements on the particular stories). There are two different SI approaches: parametric and nonparametric approaches (Bani-Hani *et al.*, 1999). The parametric SI approach identifies certain properties of the dynamic system to be modeled, e.g. stiffness and damping parameters of a building (Jalili-Kharaajoo, 2004). The nonparametric SI approach uses a black box model that is trained using the input-output relationship of the structural system (Filev, 1991). The nonparametric SI generally does not require accurate physical representation of the structure. Therefore, it is easily applicable to nonlinear modeling of the structural system, which has previously been successfully performed with neural networks and fuzzy logic systems.

One of the most commonly used nonparametric approaches of SI is fuzzy inference system which uses fuzzy set theory to build a set of rules. This can be effective in dealing with nonlinearities and uncertainties of dynamic systems (Gu & Oyadiji, 2008). Fuzzy logic has been used for many SI problems (Takagi & Sugeno, 1985; Yan & Langari, 1998; Kim *et al.* 2011) since the pioneering work of Zadeh (1965). Studies on Takagi-Sugeno (TS) fuzzy models conducted in recent years mostly deal with effective representation of nonlinear systems using fuzzy sets, fuzzy rules and a set of local linear models (Filev, 1991; Golparakrishnan *et al.* 2010; Johansen & Babuska, 2003). One of the main applications of fuzzy logic theory has been nonlinear fuzzy control system design in the field of large-scale infrastructure (Guo *et al.* 2011; Kim *et al.* 2009; Mitchell *et al.* 2012). Estimation of the parameters of a fuzzy inference system requires many trials and errors. Hence, neural networks have been used to determine these parameters.

Artificial neural networks (ANN) was developed inspired by the cognitive mechanism of the human brain (Wang *et al.* 2009). An ANN consists of linked nodes, where each node computes an output from its input. A link is created between each two nodes and the output from one node is fed in to other nodes. By adjusting the parameters of the network, the performance of the ANN improves, resulting in a more accurate model. Since ANN models are black box models, it is challenging to design them in a transparent way.

Adaptive neuro-fuzzy inference system (ANFIS) is the result of integrating features of ANN and fuzzy logic models to produce an effective SI model. Although the application of ANFIS for SI in civil engineering has been studied widely, it is still a relatively new research topic (Gu & Oyadiji, 2008; Golparakrishnan, 2010; Schurter *et al.* 2000; Ozbulut *et al.* 2007; Hakim & Abdul Razak, 2013). The main advantages of this modeling technique is to create nonlinear functions using adjustable parameters which include types and the number of membership functions (MF), learning process step size and number of epochs. A main disadvantage of the ANFIS model is that it can be computationally expensive or time-consuming (Wang *et al.* 2009). In real time situations or when dealing with large sets of data, this method can fall out of favor. To resolve this problem, principal component analysis (PCA) is integrated with ANFIS model to reduce the computation load.

PCA was first introduced in the context of data fitting by Pearson (1901). This method has been extensively used for dimensional reduction of measurement data in diverse fields (Jolliffe, 2002). This method can be used to decrease the amount of data needed for further use by discarding redundant data or variables that are less important. Examples of applications of PCA in the field of health monitoring and control of civil engineering includes the work of Sharifi *et al.* (2010) in sensor fault isolation and detection, Kuzniar and Waszczyszyn (2006) in identifying natural periods of buildings from measured data, Mujica *et al.* (2010) and Park *et al.* (2007) to assess and detect damages in civil infrastructure.

18 more pages are available in the full version of this document, which may be purchased using the "Add to Cart" button on the publisher's webpage:

www.igi-global.com/chapter/nonlinear-system-identification-of-smart-buildings/178437

Related Content

A Novel Sparse Representation Based Visual Tracking Method for Dynamic Overhead Cranes: Visual Tracking Method for Dynamic Overhead Cranes

Tianlei Wang, Nanlin Tan, Chi Zhang, Ye Liand Yikui Zhai (2019). *International Journal of Ambient Computing and Intelligence* (pp. 45-59).

www.irma-international.org/article/a-novel-sparse-representation-based-visual-tracking-method-for-dynamic-overhead-cranes/238053

Evolutionary Algorithms: Concepts, Designs, and Applications in Bioinformatics

Ka-Chun Wong (2016). *Handbook of Research on Advanced Hybrid Intelligent Techniques and Applications* (pp. 190-215).

www.irma-international.org/chapter/evolutionary-algorithms/140455

New Approach of Diagnosis by Timed Automata

Olfa Azzabi, Chakib Ben Njimaand Hassani Messaoud (2017). *International Journal of Ambient Computing and Intelligence* (pp. 76-93).

www.irma-international.org/article/new-approach-of-diagnosis-by-timed-automata/183621

Ordered Intuitionistic Fuzzy Soft Sets and Its Application in Decision Making Problem

Pachaiyappan Muthukumarand Sai Sundara Krishnan Gangadharan (2018). *International Journal of Fuzzy System Applications* (pp. 76-98).

www.irma-international.org/article/ordered-intuitionistic-fuzzy-soft-sets-and-its-application-in-decision-making-problem/208629

A Novel Approach With Dynamic Fuzzy Inference for Big Data Classification Problems

Shangzhu Jinand Jun Peng (2020). *Innovations, Algorithms, and Applications in Cognitive Informatics and Natural Intelligence* (pp. 43-58).

www.irma-international.org/chapter/a-novel-approach-with-dynamic-fuzzy-inference-for-big-data-classification-problems/247896