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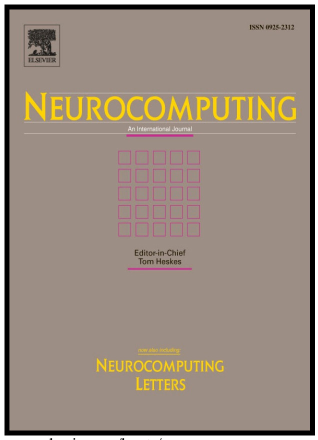

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Identification of nonlinear aeroelastic system using fuzzy wavelet neural network

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Abstract

This paper presents a novel fuzzy wavelet neural network structure to identify the nonlinear uncertain aeroelastic system. The identified aeroelastic system considers stiffness, damping non-linearity, dead zones and uncertainties. The proposed fuzzy wavelet neural network (FWNN) is developed from the interval type-2 fuzzy logic system which has the advantage to model uncertainties. Additionally, taking the rapidity and accuracy of the identification into account, the system is characterized by a set of fuzzy IF-THEN rules, and the consequent parts of which is designed to be single hidden layer wavelet neural network. And then, the sliding mode algorithm based on Lyapunov stability theory is introduced to obtain parameter update rules. Furthermore, numerical simulation for a structurally nonlinear prototypical two-dimensional wing section is investigated to verify the effectiveness of the proposed method.

Keywords: Nonlinear aeroelastic system, Fuzzy wavelet neural network, Sliding mode algorithm, Lyapunov stability theory

1. Introduction

Aeroelasticity is the field of study that deals with the interaction of structural, inertia, and aerodynamic force, and has been used in some practical applications within the area of architectural design, aviation technology, and mechanical engineering [1, 2, 3]. Extensive research has been developed to underlay physics of aeroelastic phenomena [4, 5]. In particular, research focus of investigators has been placed on the role of nonlinearity in aeroelastic system (AE system) [6, 7, 8, 9]. In transonic flow regimes, the nonlinearities in aerodynamics cannot be ignored due to the presence of shock oscillations; while in low speed regimes, linear aerodynamics is usually assumed, and nonlinear behavior in aeroelasticity arises from the structure. In the structure, nonlinearities can be classified as polynomial springs or piece-wise linear types, such as freeplay or hysteresis. It is well known that accurate identification is crucial for the control and stability of the nonlinear AE system.

In the past few years, a class of nonlinear models called block-oriented, which consists of the interconnection of linear time invariant (LTI) systems and memoryless nonlinearities were used to identify the nonlinear AE systems [10, 11]. These studies focus on the identification of block-oriented models based on an N-point data record of observed input-output measurements from an AE system. In addition, freeplay nonlinearity can occur in the control surfaces or components with loose joints. It has been observed that even a small amount of freeplay could lead to limit cycle oscillations (LCOs). A nonparametric method was investigated in [12] to identify an AE system with freeplay nonlinearity in the pitch degree-of-freedom. However, the selection of kernel function bandwidth requires a lot of engineering experience and has a significant effect on the locations of the switching points.

Besides nonlinearities, AE system is also affected by various uncertainties in nature. Uncertainties in the AE system arise from the influence of unsteady aerodynamics, stiffness, damping, sensor, actuator configuration and other control systems, and they need to be determined according to the characteristics of specific issues and engineering experience. In recent years, a variety of model validation and control method for AE systems have been presented, such as stiffness, damping non-linear [13, 14], and uncertainties [15]. For uncertain systems, a time-domain method has been presented in [16] to identify the size of uncertainty of the aeroelastic model which is a block-oriented structure containing the nonlinear part of the AE system. However, it is a challenging work to obtain an accurate model of the AE system due to the nonlinear, uncertain characteristics, and the absence of prior knowledge in many practical plants.

The AE system in this paper is a structurally nonlinear prototypical two-dimensional wing section proposed in [17], containing stiffness, damping non-linearity, dead zones and uncertainties. In fact, it is difficult to adequately capture dynamic characteristics of nonlinear plants. Many methods have been proposed to deal with these limitations. A novel approach was proposed to identify a Hammerstein model using functional link artificial neural network [18, 19]. In order to enhance the nonlinear mapping capability of the network, the system without the hidden layer expands input vector into a high dimensional space, only through a series of linear independent equations. At present, one of the trends is to combine the wavelet analysis, fuzzy logic and neural networks to produce a fusion method [20, 21]. Based on the Takagi-Sugeno-Kang (TSK) model, [22] presented a single-hidden-layer fuzzy recurrent wavelet neural network (SLFRWNN) structure. The biggest feature of the structure is the improvement of the consequent part of fuzzy

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