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Non-parametric modelling of a rectangular flexible plate structure

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ABSTRACT

This research investigates the performance of dynamic modelling using non-parametric techniques for identification of a flexible structure system for development of active vibration control. In this paper, the implementation details are described and the experimental studies conducted in this research are analysed. The input–output data of the system were first acquired through the experimental studies using National Instruments (NI) data acquisition system. A sinusoidal force was applied to excite the flexible plate and the dynamic response of the system was then investigated. Non-parametric modelling of the system were developed using several artificial intelligent methodologies namely Adaptive Elman Neural Networks (ENN), Backpropagation Multi-layer Perceptron Neural Networks (MLPNN) and Adaptive Neuro-Fuzzy Inference System (ANFIS). The performance of all these methodologies were compared and discussed. Finally, validation and verification of the obtained model was conducted using One Step Ahead (OSA) prediction, mean squared error (MSE) and correlation tests. The prediction ability of the model was further observed with unseen data. The results verified that the MLPNN converge to an optimum solution faster and the dynamic model obtained described the flexible plate structure very well. The non-parametric models of the flexible plate structure thus developed and validated will be used as the representation of the transfer function of the system in subsequent investigations for the development of active vibration control strategies for vibration suppression in flexible structures.

1. Introduction

In the past three decades, the use of flexible structure systems has been growing quickly in many engineering applications. The elements for flexible structure such frames, shells, beams and plates are extensively used in a wide range of manufacturing applications and particularly in mechanical, civil, marine, aeronautical, aerospace and other areas of practical attention, for example, flexible manipulators of satellites, solar panels, etc.

Plates with different shapes, boundary conditions at the edges and various complicated effects have often found applications in different structures such as aerospace, machine design, telephone industry, nuclear reactor technology, naval structures and earthquake-resistant structures. Particularly, the dynamic behaviour of flexible, flat, thin, rectangular plates has received huge attention in recent years because of its technical importance (Chakraverty, 2009).

The flexible thin rectangular plates structures are the most commonly used in the industrialised world and in abroad range of engineering applications, for examples, electronic circuit board design, solar panels and bridge decks. The stability of the plate, where it is subjected to loading, would be associated with a range of physical effects that lead to high vibration. The high vibration of flexible structure systems cause noise, fatigue, wear, destruction, human discomfort and reduced system effectiveness. That is why the vibration of flexible structure needs to be controlled. Due to its multiple practical problems and applications, the vibration of the elastic plates has been treated widely from researchers with different boundary conditions, both from theoretical and experimental points of view (Chakraverty, 2009). It is necessary to find an approximate or accurate model of the plate structure to control the vibration of a plate well. Suitable modelling of a dynamic system, for instance a flexible plate, would result in good control (Tavakolpour et al., 2010).

In the initial stages, results were available for some simple cases, namely a limited set of boundary conditions and geometries, in which the analytical solution could be found. With the advent of fast computers and various efficient numerical methods, there has been a big increase in the amount of research done for getting better accuracy in the results. Numerical methods offer reasonable and accepted solution but with complex shapes of plate sometimes lead to inaccuracies and more computing time (Chakraverty, 2009).

To predict the physical system behaviour under different operating conditions or to control it, a model can be created using an approach called system identification.

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In the present decade, system identification techniques have become potential candidates to many control application. Parametric and non-parametric system identification methods used to find approximate or accurate models of dynamic systems depend on observed inputs and outputs (Mat Darus, 2004). The major aim of system identification is to locate approximate or accurate models of dynamics systems depend on observed inputs and outputs. A number of researchers have applied techniques to solve the problems related to system identification. Several methods have been devised to find out models that describe input output behaviour of a system well (Ismail et al., 2006a).

Ismail et al. (2006a) have reported identification algorithms of flexible structure using Neural Networks. The research reported a study into the development of system identification methods for dynamic modelling and characterisation of flexible plate structures. The research uses Least Squares and Recursive Least Squares to find linear parametric model of the system. In addition, non-parametric models of the system are developed using Elman Neural Networks (ENN) and Multi-layer Perceptron Neural Networks (MLPNN; Ismail et al., 2006a).

Mohd Hashim et al. (2004) have reported non-linear dynamic modelling of flexible beam structures using Neural Networks. The research investigated the utilisation of neural network (NNs) backpropagation for modelling flexible beam with fixed-free mode. Comparative analysis of the performance of the Recursive Least Squares scheme and intelligent Neural Networks model in characterizing the system was carried out in the frequency and time domains. Simulated results have shown that by Neural Networks the system is modelled better than with the conventional linear modelling method (Mohd Hashim et al., 2004).

Mat Darus et al. (2008) have reported Adaptive Neuro-modelling of a twin rotor system. The research investigated the utilisation of Adaptive Neural Networks (NNs) for dynamic modelling and identification of a highly non-linear TRMS system. An adaptive Elman neuro-model is designed to characterise a twin rotor multi-input multi-output system (TRMS) in vertical motion based on one step-ahead (OSA) prediction. The results obtained, in both frequency and time domains, are compared to the identification using the conventional adaptive technique of Recursive Least Squares (RLS). Simulations indicate the superiority of an adaptive neuro-modelling technique over RLS algorithm in modelling and identification of the TRMS (Mat Darus et al., 2008).

Ismail et al. (2006b) have reported dynamic characterisation of flexible vibrating structures using adaptive neuro-fuzzy inference system (ANFIS). In this research ANFIS was used to develop a model characterizing the vibration of the plate. The input/output data used in this research was obtained from a simulation of a square, flat, flexible plate with all edges clamped using finite difference (FD) algorithm (Ismail et al., 2006b).

Toha et al. (2008) have reported ANFIS modelling of a twin rotor system. An Adaptive Neuro-Fuzzy Inference System (ANFIS) network design is deployed and used for modelling a twin rotor multi-input multi-output system (TRMS). It is demonstrated experimentally that ANFIS can be effectively used for modelling the system with highly accurate results. The accuracy of the modelling results is demonstrated through validation tests including training and test validation and correlation tests (Mat Darus and Tokhi, 2006).

System identification is a broad idiom used to describe algorithms and mathematical tools that build dynamical models from measured data. Over the last two decades system identification has received a lot of attention. System identification methods are widely used as a fundamental requirement in scientific applications and engineering. The practical application domains include the Boolean function generation, symbolic regression and pattern recognition and time-series prediction. The problem of finding an approximate or accurate model for dynamical systems occurs often in engineering applications. System identification is one way to solve this problem (Ismail et al., 2006a).

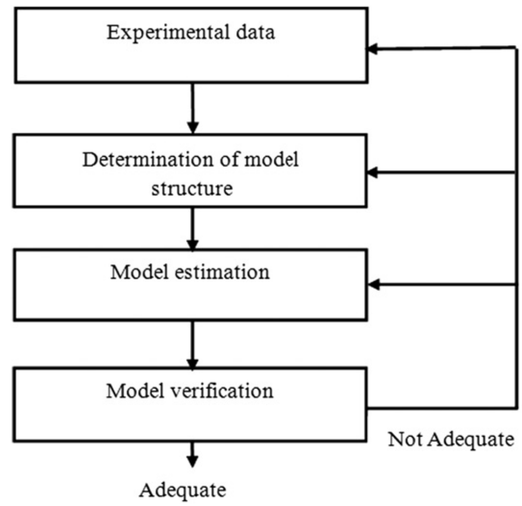

Fig. 1. Schematic description of the system identification procedure.

The major aim of system identification is to find approximate or accurate models of dynamic systems depend on observed inputs and outputs. When a model of the physical system is obtained, it can be used for solving different problems; such as to predict its behaviour under different operating conditions or control the physical system. Numerous researchers have applied techniques to solve the system identification problems. A number of methods have devised to obtain models that best describe input output behaviour of a system.

The reason of this study is to develop a model characterizing vibration of two-dimensional flexible rectangular plate structures using non-parametric identification techniques as soft computing. In this work, a thin rectangular plate with all edges clamped is considered. Prior to this, a dynamic model of the plate structure based on laboratory experiments characterizing the flexible plate structure is developed. Finally, the validity of the obtained model was investigated using correlation tests. The procedure of system identification can be represented as shown in Fig. 1.

2. Experimental setup

From theoretical and experimental points of view, the vibration of the flexible plates has been treated extensively. The vibration of a plate can be excited and detected with a suitable experimental setup. Accurate understanding of the results allows us to achieve useful information. Several researchers made experimental studies with different types of setup and instrumentation to measure the vibration parameters and to control the plate (Shimona et al., 2005; Shimon and Hurmuzlu, 2007; Qiu et al., 2009).

In this investigation, the input–output data of the system were first acquired through the experimental studies using National Instruments (NI) data acquisition system. To provide experimental data, a rectangular plate with dimensions of 1 m × 1.5 m × 0.003 m was investigated. To allow a 0.04 m width clamped boundary on all four sides, the rectangular plate was cut as 1.58 m × 1.08 m. The experimental arrangement developed for this study was established as shown in Fig. 2.

To acquire the perfect conditions of clamped boundaries, four steel bars with rectangular cross sections were used to clamp the plate edges giving 40 mm as the thickness of the clamped