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Active vibration control of flexible cantilever plates using piezoelectric materials and artificial neural networks

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ABSTRACT

The study presented in this paper introduces a new intelligent methodology to mitigate the vibration response of flexible cantilever plates. The use of the piezoelectric sensor/actuator pairs for active control of plates is discussed. An intelligent neural network based controller is designed to control the optimal voltage applied on the piezoelectric patches. The control technique utilizes a neurocontroller along with a Kalman Filter to compute the appropriate actuator command. The neurocontroller is trained based on an algorithm that incorporates a set of emulator neural networks which are also trained to predict the future response of the cantilever plate. Then, the neurocontroller is evaluated by comparing the uncontrolled and controlled responses under several types of dynamic excitations. It is observed that the neurocontroller reduced the vibration response of the flexible cantilever plate significantly; the results demonstrated the success and robustness of the neurocontroller independent of the type and distribution of the excitation force.

1. Introduction

Engineers are employing lightweight materials and thinner structures in their designs in an attempt to reduce the construction cost and increase the efficiency of the design. However, flexible structures with smaller damping and lighter masses are more vulnerable to dynamic loading induced by environment conditions and human activities [1,2]. The control of vibrations due to the dynamic forces has always been a concern for engineers. Therefore, it is necessary to design and implement efficient vibration control techniques to enhance the serviceability and extend the life-cycle of structures [3]. Vibration control systems are classified according to their dynamics and energy requirements into passive, semi-active, and active systems [4]. Active vibration control systems utilize a network of sensors and actuators to measure the structural response and produce control forces in a prescribed manner to dissipate the energy and reduce the response of the host structure [5].

Flexible plates, particularly cantilever plates, are among the most commonly used flexible members in aerospace structures and aircrafts. Consequently, extensive research has been conducted on vibration control of flexible plates. One of the most interesting and feasible active control configurations in this field includes the implementation of the excellent sensing and actuating properties exhibited by piezoelectric materials [6,7].

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Several researchers have utilized piezoelectric materials in the form of piezoelectric patches as both actuators and sensors to develop different active control schemes for vibration control of flexible plates. The most pronounced difference between these schemes is the control algorithm that is implemented to determine the appropriate control voltage signal applied on the piezoelectric actuators. Caruso et al. [8] have studied the active vibration control of cantilever plates employing multiple piezoelectric sensor/actuator pairs. They applied H_2 control techniques to create multiple controllers to control the voltage applied on the actuators. Similarly, Qiu and Haraguchi [9] employed piezoelectric patches along with a controller that utilizes finite impulse response filter and the filtered-X LMS algorithm to control the response of flexible plates. Sadek et al. [10] used piezoelectric patch actuators for active control of simply supported flexible plates. An optimal control law was derived explicitly using the maximum principle theory to compute the voltage applied on the actuators. In an experimental study, Qiu et al. [11] investigated the optimal placement of piezoelectric sensors and actuators for active control of a cantilever plate. After that, they combined positive position feedback with a PD controller to suppress the plate's response. The efficiency of this control methodology was demonstrated analytically and experimentally. In another study [12], the same authors have integrated piezoelectric patches with gyroscope sensor to control bending and torsional vibrations of cantilever plates. Sensors and actuators were optimally placed such that the vibration modes can be decoupled. A discrete-time sliding mode variable structure control algorithm was used to drive the piezoelectric actuators. Additionally, other control algorithms have been utilized for active control of plates using piezoelectric actuators such as proportional iterative learning algorithm [13] and nonlinear fuzzy control [14].

1.1. Neural networks for active vibration control

Artificial neural networks are black-box models consisting of processing units interconnected according to an architecture that is based on human's central nervous system [15]. Neural networks have been utilized in several areas of engineering applications such as medical diagnoses, computer vision, pattern recognition, and speech pronunciation. In civil, mechanical and aerospace engineering, neural networks have been applied in design optimization, structural health monitoring, structural system identification, and finite element mesh generation [16].

Neural networks are also widely used in the vibration control field. Several applications of neural networks for active and semi-active vibration control of civil and mechanical systems can be found in the literature. For instance, Bani-Hani and Sheban [17] have developed a neural network based controller (i.e. neurocontroller) for semi-active base isolation of a frame structure equipped with magnetorheological (MR) dampers. The neurocontroller was trained based on an LQG controller to compute the optimal voltage command applied on the MR dampers. In another analytical study, Xu et al. [18] used neural networks for active control of a hypothetical cable-stayed bridge. The stay cables were modeled as active tendons attached to actuators that provide the control forces. The force generated by each single actuator was controlled by a decentralized neurocontroller.

Recently, neural networks have been used in applications related to active control of flexible plates using piezoelectric sensors and actuators. Qiu et al. [19] have utilized a proportional-derivative (PD) controller for vibration suppression of a smart beam consisting of a cantilever flexible beam featuring a number of piezoelectric sensor/actuator pairs. A back-propagation neural network (BPNN) was used to update the parameters of the PD controller online. This BPNN-PD algorithm was applied to compute the optimal voltage signal applied on the piezoelectric actuator. Similarly, Mohit et al. [20] studied the control of a cantilever plate using a neurocontroller and piezoelectric patches. This neurocontroller was trained and tuned based on an LQR controller. Clearly, the aforementioned two studies have used control algorithms that integrate neural networks with conventional controllers (PD and LQR controllers).

Alternatively, there are a few intelligent control algorithms available in the literature that depend only on neural networks and do not require other controllers such as model-reference neural control [21], neural network predictive control [22], and NARMA-L2 algorithm [23]. Another interesting example here is the neural network based control algorithm which has been developed by Ghaboussi and Joghataie [24] and used for active control of a multi-story shear frame using hydraulic actuators. This algorithm was improved later by Bani-Hani [25] and used for the same application. As will be explained in Section 3, this algorithm requires training a neurocontroller based on a set of emulator neural networks that are designed to predict the future response of the controlled system.

The study presented in this paper utilizes a modified version of the abovementioned neural network based control algorithm to introduce a new intelligent methodology for vibration suppression in smart cantilever plates. Based on a set of emulator neural networks, a neurocontroller is designed to compute the optimal voltage applied on the piezoelectric patches. In order to formulate the model required for simulations and controller design, a finite difference method is applied on the equations governing the response of a cantilever plate under the effect of both piezoelectric patches and external excitations. Finally, numerical simulations are carried out to verify the model and examine the efficiency of the proposed active control technique.

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