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Fine tuning of a fuzzy controller for vibration suppression of smart plates using genetic algorithms

G. Tairidis[a], G. Foutsitzi[b], P. Koutsianitis[a], G.E. Stavroulakis[a,*]

[a] Technical University of Crete, School of Production Engineering and Management, GR-73100 Chania, Greece
[b] Department of Accounting and Finance, Technological Educational Institution of Epirus, TEI Campus – Psathaki, GR-48100 Preveza, Greece

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ABSTRACT

Piezoelectric sensors and actuators are used for vibration control and suppression of a smart composite plate. In the present paper, the vibration suppression of smart structures using intelligent control strategy is considered. A smart plate described by Mindlin plate theory is used in the finite element modeling of laminates with piezoelectric layers. The control is based on a set of fuzzy rules that combine the membership functions of the system variables by using fuzzy inference techniques. A genetic algorithm is used in order to optimize the parameters of the fuzzy controller. The numerical results indicate that the problem statement is successful and the proposed method is very efficient. In addition, the results obtained are very satisfactory compared to previous investigations of our team. All implementations are built and tested within MATLAB environment.

1. Introduction

Vibration control of smart mechanical structures is the subject of scientific research for many years. However, the industrial evolution of the last decades has raised dramatically the complexity of systems studied. Thus, plenty of different optimization methods are used in order to design and/or fine tune control schemes. Optimization methods inspired by nature are very popular due to their simplicity and effectiveness in different problems and situations.

The optimization process using genetic algorithms present a great distribution of application in a plethora of different fields and, of course, in structural control. For instance, PID control is one of the most common and powerful control methods in automatic control. However due to the complexity of modern industrial systems, nonlinearities and other flaws may occur, rendering the controllers less powerful and holding back the control process. Thus, the optimization of the parameters of such controllers is necessary. For the optimal design of intelligent PID controllers genetic algorithms may be used [1].

Besides classical mathematical control methods, which usually provide satisfactory results in case of linear feedback laws under certain assumptions, the implementation of nonlinear controllers based on fuzzy techniques is proposed in previous investigations [2].

The term fuzzy introduced, back in 1973, by Professor L. Zadeh [3] who proposed the linguistic representation of variables creating fuzzy sets governed by a set of rules of inference of the known if-then form. The main principles of fuzzy control can be found in [4,5]. The application of fuzzy logic in control systems and a general methodology for constructing a fuzzy logic controller can be found in [6].

The fuzzy logic can be used in combination with genetic algorithms optimization techniques in several applications. For example genetic algorithms can be applied in mathematical modeling, for the training of fuzzy systems [7], in structures, for the optimization of active control of high rise building structures [8] or in chemical industry, for example in order to establish suitable control of pH [9].

As for the design of fuzzy logic controllers by using genetic algorithms, a simple method with symmetrically distributed fuzzy sets is presented in [10], where the problem is considered to be a mixed integer constrained dynamic optimization problem. Regarding the tuning of fuzzy controllers, genetic algorithm can be used in order to increase their performance in the control process [11] and to optimize their parameters [12].

Various investigations regarding application of fuzzy control by using piezoelectric sensors and actuators in order to reduce the vibration of plates have been done [13,14]. In [15] two numerical schemes for vibration suppression of smart plates using fuzzy control, are presented. In [16] active vibration control of a rectangular

* Corresponding author. Tel.: +30 2821037418; fax: +30 2821006900.
E-mail addresses: tairidis@gmail.com (G. Tairidis), gfoutsi@teiep.gr (G. Foutsitzi), panoskout@gmail.com (P. Koutsianitis), gestavroulakis@isc.tuc.gr, gestavr@mycosmos.gr, gestavr@dpem.tuc.gr (G.E. Stavroulakis).

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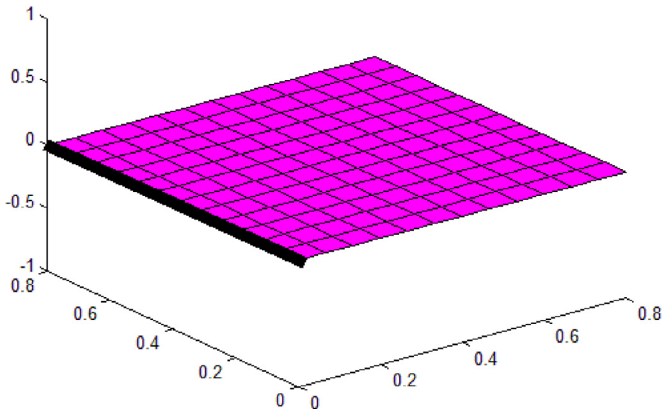

Fig. 1. The plate model.

plate using fuzzy logic control is investigated in comparison to the application of PID control and in [17] a fuzzy logic based independent modal control of vibration of plates is considered.

In the present paper, fuzzy techniques on smart structures are applied and tested. This work is a continuation of a previous publication of our team [13] at the Twelfth International Conference on Computational Structures Technology, held in Naples on 2–5 September 2014.

The mechanical model consists of a composite plate, fixed at one end, on which piezoelectric sensors and actuators are attached. The plate is discretized with use of the finite elements method and is subjected on a sinusoidal loading. The fuzzy system that is used for control was implemented and tested in [2,13,18]. The fuzzy controller is adjusted in order to operate properly with the plate model.

Furthermore, a global optimization method, namely a genetic algorithm is used in order to optimize the membership functions of the fuzzy inference system that describe the controller proposed. The control scheme and the numerical integration algorithm that used for the vibrations suppression of the composite plate, as well as, the genetic algorithm that used for the fine tuning of the fuzzy controller were built within MATLAB environment.

2. Model and control

2.1. The smart plate model

Fig. 1 shows a schematic of the smart plate considered in this work. The length, width and thickness of the whole plate are denoted by L, b and h_c, respectively. Two piezoelectric layers of thickness h_p are symmetrically bonded perfectly on the top and bottom surface of the host composite plate. The top layer acts like a sensor and the bottom one as an actuator. The poling direction of the piezoelectric actuator is assumed to be along the z-axis. An electric field E_z is applied along the poling direction of the actuator by applying a voltage V between the upper and lower electrodes of the actuator, with $E_z = V/h_p$. Because of the piezoelectric properties of the piezo-layers, the actuator will perform in both x and y directions and therefore, induce deformation of the whole structure [19].

Table 1
Fuzzy inference rules (e.g. if displacement is far up and velocity is up then the control force is max).

Velocity	Displacement				
	Far up	Close up	Equilibrium	Close down	Far down
Right	Max	Med+	Low+	Null	Low−
Null	Med+	Low+	Null	Low−	Med−
Left	High+	Null	Low+	Med−	Min

A standard finite element, Mindlin plate model was developed to design the plate [20]. Four-node bilinear isoparametric elements with five degree of freedom at each node were used. The equations of motion that describe the dynamical behavior of the plate are derived from Hamilton's principle and are given by

$$M \cdot \ddot{u} + C \cdot \dot{u} + K \cdot u = P + Z \quad (1)$$

where M is the mass matrix, C is the Rayleigh-damping matrix, K the stiffness matrix, P the loading vector and Z the control force vector. With u, $\dot{u}$ and $\ddot{u}$ we denote the displacement, the velocity and the acceleration, respectively.

The main objective is to design control laws for the smart plate subjected to external induced vibrations. For this purpose, a fuzzy control system is applied in this work.

2.2. Fuzzy control

The fuzzy inference system shown in Fig. 2 is developed within MALAB using the fuzzy toolbox. The control scheme consists of a Mamdani-type controller of two inputs and one output. As for inputs, the controller takes displacement and velocity and returns the control force.

The membership functions used are triangular and trapezoidal ones both for inputs and output and are shown in Fig. 3. The inference system involves membership functions combined with use of logical operations.

Namely, the decision is based on a set of if-then rules, thus the recurring system is a rule-based system. A set of 15 rules was used as shown in Table 1, with weights equal to unity and are connected using the AND operator. The graphic representation of rules is shown in Fig. 3.

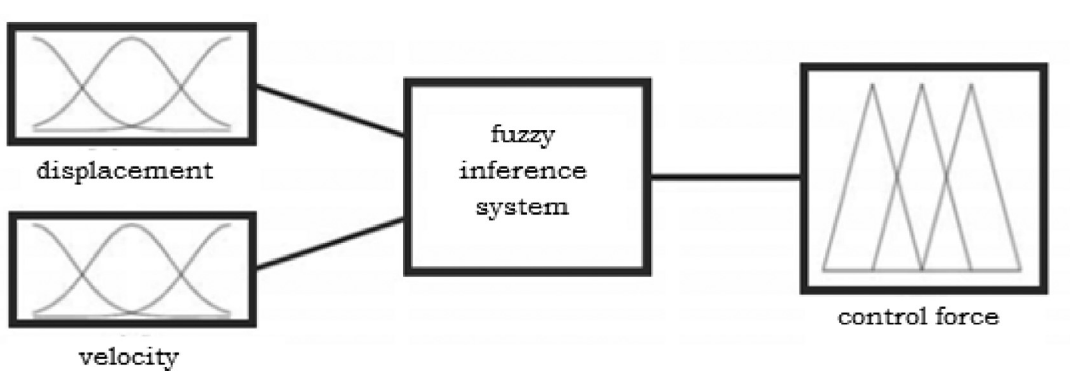

Fig. 2. Mamdani fuzzy inference system.