Neuro-Fuzzy Active Vibration Control of Flexible Structure

A. Y.Ismail[1]*, I. Z. Mat Darus[2] and N. A. Che Zakaria[1]

[1]Center of Excellence for Humanoid Robots & Bio-Sensing Center (HuRoBs), Faculty of Mechanical Engineering, Universiti Teknologi MARA, Malaysia
[2] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia
*E-Mail: yusri3598@salam.uitm.edu.my

Summary: Flexible plate structures have broad applications, ranging from industrial area to space technology. The demand for thin, flexible plate structure has rapidly increased due to industrial evolutions. However, this type of structure leads to high vibration. There are numerous research and study that have been conducted to analyze this problem. The aim of this study is to develop a model characterizing the vibration of a 2-dimensional flexible plate using adaptive neuro-fuzzy inference system (ANFIS). In order to construct the model, sets of data were obtained from numerical analysis. Finite difference method was implemented to discretize the dynamic equation of the plate to finite difference equations. Simulation algorithm was then developed and implemented within the MATLAB environment. The results obtained were validated by comparing the first five frequency parameters with values from other researchers. The sets of data obtained were utilized to develop ANFIS model. The performance of the system was assessed. The results suggest that ANFIS model is a good tool in system modeling and vibration control.

Keywords: Flexible, Modelling, Adaptive Control, Vibration.

1. Introduction

Plate structures are widely used around the world, predominantly in engineering fields. The structures have been extensively applied to civil, aerospace and mechanical, automotive and marine engineering. The importance of flexible plate structure has emerged in recent years due to its broad application in industries and also areas where precise operation performances is vital such as automation, aerospace systems, satellites flexible manipulators, solar panel and electronic circuit board design [1][4]. The increasing usage of flexible plate in various applications leads to the demand of having reliable, light and efficient flexible structure. However, thin, light and large structure leads to high vibration. The vibration of the structure is lightly damped due to the low internal damping of material used [2].

Active vibration control (AVC) is a tool that can be used to control the unwanted vibration. Therefore active vibration control has become the topic of interests among scientists and engineers due to the capabilities and potentials it has. AVC involves generating destructive source(s) to interfere with the unwanted signals and result in a reduction in the level of the vibration at desired location(s) [4].

A method which combines the natural system dynamics and an intelligent machine is known as soft computing. The well-known neural networks and fuzzy logics fall in this intelligent method [3]. Then, single-input single-output (SISO) control structure was utilized to develop the AVC system [4]. The purpose of this study is to develop a neuro-fuzzy model of a 2-dimensional flexible square plate structure. The model will adapt adaptive neuro-fuzzy inference system (ANFIS) concept. The first part of this project involves developing a model characterizing the vibration of the plate using finite difference (FD) method. The sets of data obtained from this FD model are used to develop and train the ANFIS model. Finally, active vibration controller (AVC) is developed utilizing the ANFIS model.

2. Methodology

The classical plate equation is given by [3]:

$$\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} + \frac{\rho}{D}\frac{\partial^2 w}{\partial t^2} = \frac{q(x,y,t)}{D} \qquad (1)$$

Finite difference method was used to solve the partial differential equation in (1). The differential equation and its boundary conditions were replaced with equivalent difference equations [6]. Using central finite differences, Equation (1) can be written as:

$$w_{i,j,k+1} = -\frac{D\Delta t^2}{\rho \Delta xy^4}\begin{bmatrix} 20w_{i,j,k} - 8\left(w_{i+1,j,k} + w_{i-1,j,k}\right) - 8\left(w_{i,j+1,k} + w_{i,j-1,k}\right) \\ + 2\left(w_{i-1,j-1,k} + w_{i-1,j+1,k} + w_{i+1,j-1,k} + w_{i+1,j+1,k}\right) \\ + \left(w_{i+2,j,k} + w_{i-2,j,k}\right) + U\left(w_{i,j+2,k} + w_{i,j-2,k}\right) \end{bmatrix}$$

$$+ 2w_{i,j,k} - w_{i,j,k-1} + \frac{\Delta t^2 q_{i,j}}{\rho} \qquad (2)$$

The algorithm was implemented within the MATLAB environment where a square aluminum, thin, flat plate has been considered. The properties of the plate are listed in Table 1.

Table 1. Properties of the plate.

Property	Value
Length	1.2 m
Width	1.2 m
Thickness, *h*	0.004 m
Young's Modulus, *E*	7.11×10^{10} N/m^2
Poisson's Ratio, υ	0.3
Mass density per unit area, ρ	2700 kg/m^2

Neuro-fuzzy model was developed using ANFIS to model the flexible square plate structure. One-step ahead (OSA) prediction was used to obtain the model of the plate from the input to the centre deflection of the plate. Figure 1 and Figure 2 present ANFIS structure with first-order Sugeno model and ANFIS membership function and rules, respectively.

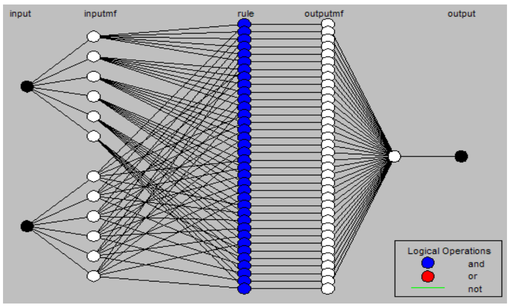

Figure 1. ANFIS network structure for modelling the flexible plate.

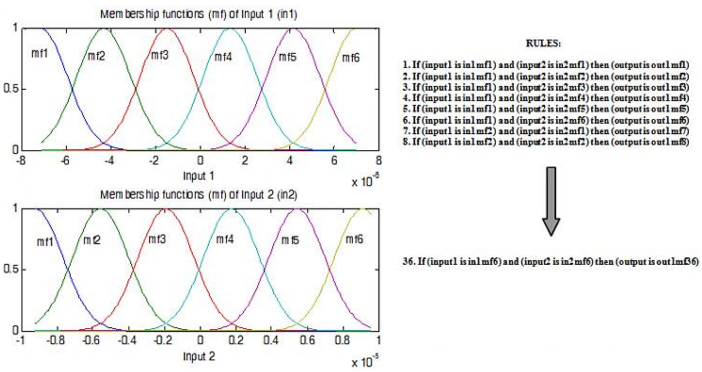

Figure 2. ANFIS membership functions and rules.

AVC mechanisms were developed based on SISO-AVC structure as shown in Figure 3. This type of structure has been applied in various noise and vibration applications [5].

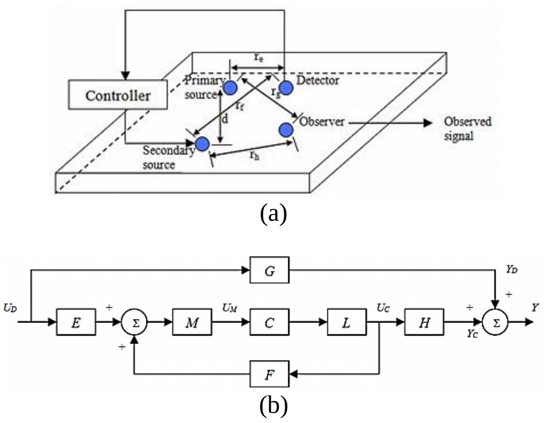

Figure 3. SISO feedforward AVC structure (a) schematic diagram; (b) block diagram.

The optimum arrangement of primary source, detection point, observation points and secondary sources on the plate, obtained by trial and error, are shown in Figure 4. Previous work utilized method such as Genetic Algorithm (GA) to optimize those locations. In this work, heuristic method was used to determine the points. Several sets of point were selected and simulated. Changes of locations produced significant difference in results. Blocks *E*, *F*, *G* and *H* are transfer functions representing distance paths of r_e, r_f, r_g and r_h respectively. The transfer characteristics of the detector, the controller and the secondary source are shown as *M*, *C* and *L* respectively. U_D and U_C are the primary and secondary signals, whereas Y_D and Y_C are the corresponding signals at the observation point, respectively. U_M is the detected signal and *Y* is the observed signal. The objective of this SISO-AVC is to force the observed signal *Y* to zero [7].

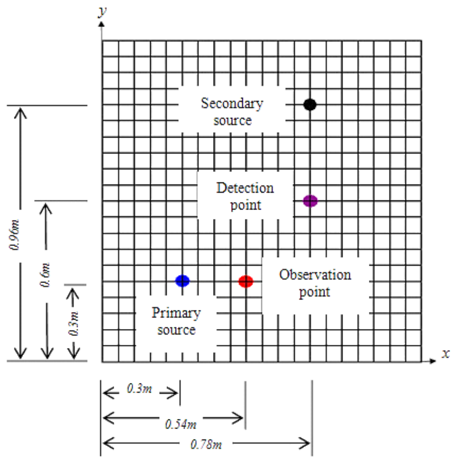

Figure 4. Arrangement of SISO-AVC points on the plate.

For online design of the controller, the system can be considered with signal at the detection point, U_M, as input while the observed signal *Y* as output. The system can be characterized by two subsystems; when the secondary source is off, and when the secondary source is on. The two subsystems are represented as Q_o and Q_1 respectively. The transfer functions for these two conditions can be written as:

$$Q_o = \frac{Y}{U_M}\bigg|_{U_C=0} \tag{3}$$

$$Q_1 = \frac{Y}{U_M}\bigg|_{U_C\neq 0} \tag{4}$$

The controller relationship is governed by

$$C = \left[1 - \frac{Q_1}{Q_0}\right]^{-1} \tag{5}$$

First, ANFIS network was trained to characterize the system models Q_0^{-1} and Q_1. Figure 5 and Figure 6 describe the two models. Then, both models were utilized to train the hybrid network, as shown in Figure 7.

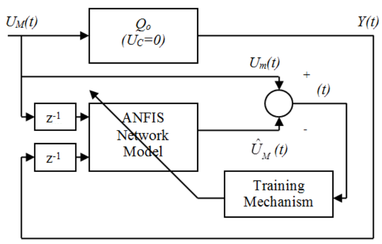

Figure 5. Modelling of the inverse plant, Q_o^{-1}.

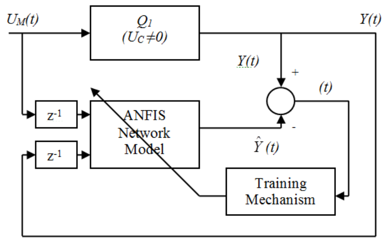

Figure 6. Modelling of the plant Q_1.

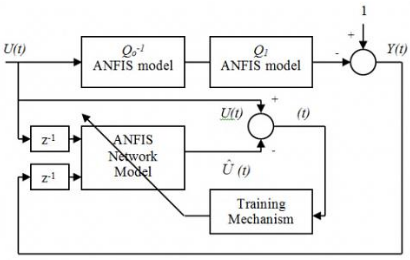

Figure 7. Training the ANFIS-AVC controller.

3. Results

The deflection of the plate with respect to time is shown in Figure 8. By using fast Fourier transforms (FFT), frequency-domain response of the plate was obtained.

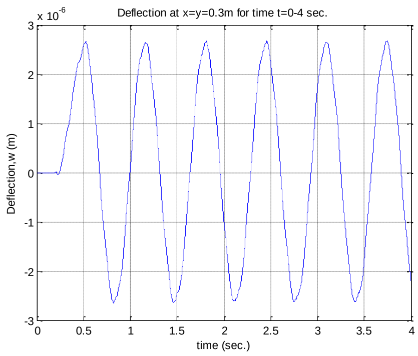

Figure 8. Plate deflection at 0.3*m* x 0.3*m*.

The performance of the systems has been assessed through spectral density and resonance attenuation. The vibration of the plate is reduced when AVC mechanisms are applied to the structure. The performance of ANFIS-AVC algorithm is presented in Figure 9, Figure 10 and Figure 11.

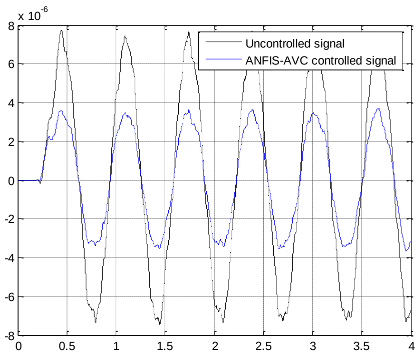

Figure 9. Time domain response of ANFIS-AVC.

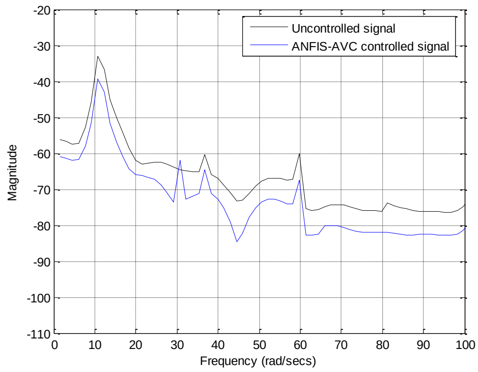

Figure 10. Spectral density.

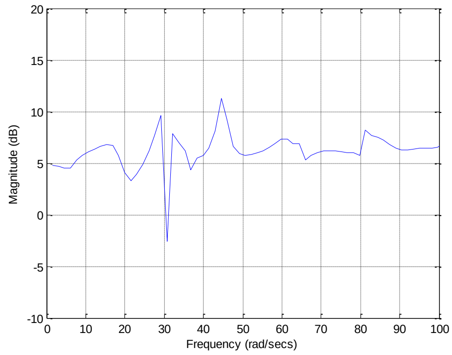

Figure 11. Spectral attenuation.

Table 2 tabulates spectral attenuation of the dominant notes obtained from the ANFIS-AVC. The results clearly suggested that ANFIS performed well, both in system representation and vibration suppression of the flexible plate structure.

Table 2. Spectral attenuation of ANFIS-AVC.

Mode	Mode 1	Mode 2	Mode 3
Attenuation (dB)	6.1	5.2	6.3

Acknowledgement

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