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ANFIS Modelling of Flexible Plate Structure

A. A. M. Al-Khafaji, I. Z. Mat Darus and M. F. Jamid
Department of Applied Mechanics,
Faculty of Mechanical Engineering,
Universiti Teknologi Malaysia,
Skudai, Johor, Malaysia.
ali1977abdalhusain@yahoo.com, intan@fkm.utm.my, ort_14@yahoo.com.

Abstract: This paper presented an investigation into the performance of system identification using an Adaptive Neuro-Fuzzy Inference System (ANFIS) technique for the dynamic modelling of a two-dimensional flexible plate structure. It is confirmed experimentally, using National Instrumentation (NI) Data Acquisition System (DAQ) and flexible plate test rig 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.

Keywords: Adaptive Neuro-Fuzzy Inference System, Dynamic modelling, System Identification, Flexible Plate, Active Vibration Control.

1. INTRODUCTION

The flexible plate structures are utilized in several applications such as airplane wings and solar panel. These applications are lead to high vibration when expose to environmental disturbances, which may cause structural fatigue, and reduce system effectiveness. Therefore, it is very important to reduce these undesirable vibrations [1].

To develop an effective control mechanism for vibration suppression, it is required to model and predict the behaviours of the system based on given input-output data [2].

System Identification was candidate for modelling linear and nonlinear systems in the past three decades. A number of researchers have been devised System Identification techniques to determine models that best describe input-output behaviour of a system. The procedure, for identifying a dynamical system based on given input-output data, consists of several steps. Firstly, acquisition of the input and output data of the system is carried out. Then, the model structure is selected. Next, the model of the system is estimated using system identification techniques. Once the model of the system is obtained, it is required to verify and validate whether the model is good enough to represent the system. A number of validation tests are available in the literature. These include correlation tests, mean square error, estimation and test data [2].

Recently, vast applications have been devised using the fusion of artificial neural network and fuzzy logic through ANFIS [3, 4, 5 and 6].

In this paper, dynamic modelling of the highly nonlinear flexible plate structure is considered using intelligent technique, namely, ANFIS. The objective of the identification experiments is to estimate a model of the flexible plate structure without any prior system knowledge pertaining to the exact mathematical model structure. The system will be validated using input/output mapping, mean-squared of error and correlation tests. The model thus developed and validated will be used in subsequent investigations for vibration suppression and control strategies for the flexible plate structure.

The purpose of this study is to develop a model characterizing vibration of a two-dimensional flexible rectangular plate structures using soft computing method through ANFIS. In this work, a thin rectangular plate with all edges clamped is considered. A dynamic model of the plate structure based on laboratory experiments characterizing the flexible plate structure is developed.

2. EXPERIMENTAL STUDY

Due to its multiple practical applications, the vibration of the flexible plates has been a subject widely treated, both from experimental and theoretical points of view. The vibration of a plate can be excited and detected with an appropriate experimental setup. A correct interpretation of the results allows us to obtain useful information. Some works are focused on free-vibration experiments; others refer to plates vibrating under external excitation [7 and 8].

In this paper, the input-output data of the data were first acquired through the experimental study using NI data acquisition system. The experimental arrangement developed for this investigation is demonstrated as shown in Fig.1 and the experimental layout shown in Fig.2

The steps that the information flow in DAQ as following:

1. Transducers: Sense physical signals and translate it into electric signals. In this paper, Piezo-beam Type Accelerometer (Kistler-8636C5) was considered.
2. Signal Conditioning: Electrical signals are conditioned in such a way that they can be used by an analog input board. Some types of signal conditioner are amplification, isolation and filtering linearization. In this research, the required signal conditioning circuits have been incorporated into the National Instrumentation

(NI) Compact-Data Acquisition unit equipped with NI-9234 module.

3. Analog to Digital (A/D) converter: An analog-to-digital converter (A/D) is a device which converts continuous signals to discrete digital numbers. In this research, an Analog to Digital (A/D) converter have been incorporated into the NI Compact-Data Acquisition system.

4. Process, analyze, store, and display the acquired data using specialised software:

In this research, the acquired signal was analyzed, stored and displayed using Intel Core TM Duo Processor with LabVIEW environment.

In this research, experiment study was implemented using NI data acquisition system and LabVIEW software in order to obtain the vibration of plate input/output data.

Fig. 1: Experimental setup [7]

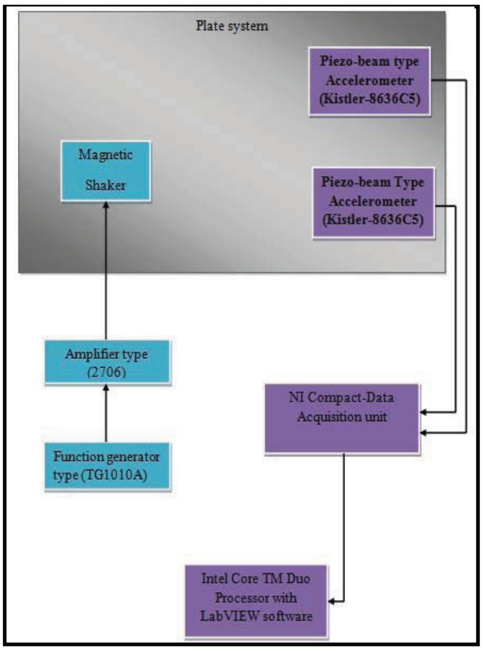

Fig. 2: Experimental setup layout

3. Adaptive Neuro-Fuzzy Inference System

The most popular members of the soft computing methodologies are neural networks and fuzzy inference systems. A neural network provides the mathematical power of the brain whereas fuzzy logic based mechanism employs the verbal power. The latter allows the linguistic manipulation of input-state-output data. The most interesting applications offer an appropriate combination of these two approaches resulting in a hybrid system that operates on both linguistic descriptions of the variables and the numeric values through a parallel and fault tolerant architecture [6].

The term ANFIS represents Adaptive-Network-Based Fuzzy Inference System, created by Jang, 1993. It is classified as a hybrid neuro-fuzzy model, constructed by combining a neural network and a fuzzy logic system into a homogeneous architecture [9]. ANFIS is proposed as a core neuro-fuzzy model that incorporates human expertise as well as repeated self-learning features into the modelling. This architecture has demonstrated a high performance in many applications [10].

The network-type structure of ANFIS is similar to that of a Neural Network. Initially, a crisp input is converted through the input membership functions and the associated parameters to fuzzy input. Then, the fuzzy input is processed through fuzzy rules to produce fuzzy output. After that, the fuzzy output is converted through the output membership functions and the associated parameters to a crisp output, as shown in Fig. 3 [11].

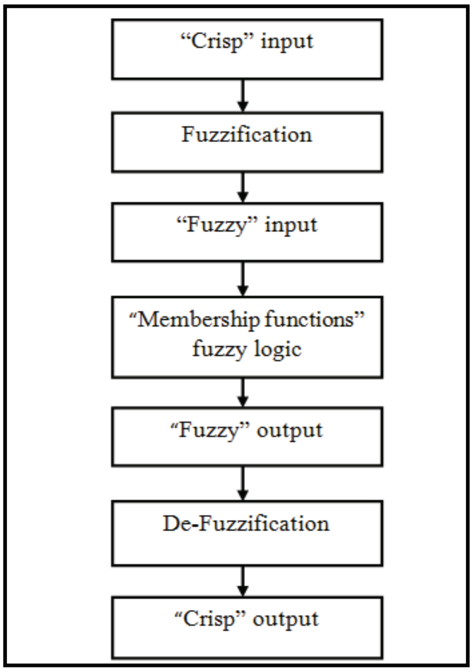

Fig. 3: ANFIS process

The working Principle of ANFIS, as described by Ismail et.al [3], is shown in Fig. 4. Fig. 5 shows the diagrammatic representation of the ANFIS algorithm.

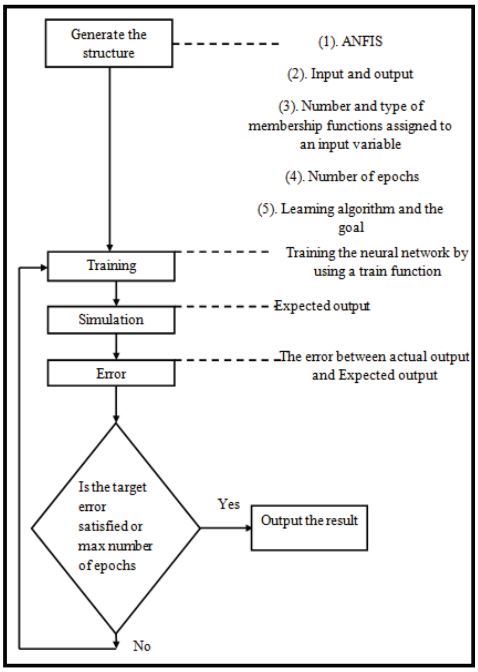

Fig. 4: Working Principle of ANFIS

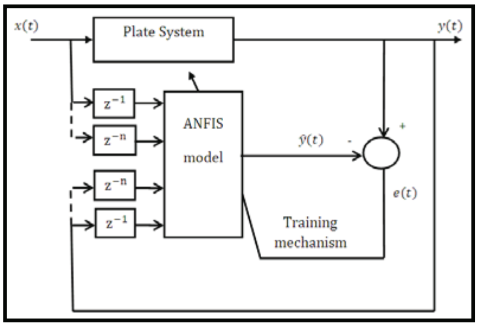

Fig. 5: The diagrammatic representation of the ANFIS [2].

ANFIS uses back propagation learning to learn the parameters related to membership functions and least mean square estimation to determine the consequent parameters. Every step in the learning procedure includes two parts. The input patterns are propagated, and the optimal consequent parameters are estimated by an iterative least mean square procedure. The premise parameters are assumed fixed for the current cycle through the training set. The pattern is propagated again, and in this epoch, back propagation is used to modify the premise parameters while the consequent parameters remain fixed [6].

4. Experimental Results

Experimental investigation was conducted to investigate the vibration of a flexible plate system. A rectangular, thin, flat aluminium plate with four edges clamped (C-C-C-C) boundary conditions is considered. The properties of the plate are listed in Table 1.

Table 1: Plate specifications

Parameter	Value
Length (a)	1.58 m
Width (b)	1.08 m
Thickness (h)	0.003 m
Density (ρ)	2690 Kg m^{-3}
Modulus of elasticity (E)	6.83 1010 N m^{-2}
Poisson ratio (υ)	0.34

The locations of sensors and actuator were assigned as shown in Fig. 6. Point (X) represented the location of the magnetic shaker (for input force). Whilst the location of sensor at point (Y) (for signal detection) and the location of sensor at point (Z) (for signal observation), were chosen in such a way that it was considerably far enough from the nodal lines defined by the first five natural frequencies of the plate as described by Tavakolpour *et. al.*[12]. This kind of arrangement was desired as the characteristics of the model learned in this setting might provide useful information in future of active vibration control (AVC). However, the best AVC can only be achieved if the model of the system could be accurately described. Therefore, an experimental study was carried out to obtain the input /output data (between detection and observation points) and these data will be used later for System Identification to obtain the best model describing the plate. The test structure was excited by a sinusoidal force generated by a magnetic shaker, which was designed and developed by Tavakolpour *et. al.* to serve as a source of vibration [12]. A sinusoidal input force (F) with an amplitude of [19 Hz, 5V] at time instance of 4 sec was applied to the excitation point (X) located at x=0.25a, and y=0.25b. The experimental lateral deflection of the plate at detection point (Y) located at x=0.75a, and y =0.75b, in time domain response is plotted in Fig. 7. The experimental lateral deflection of the plate at observation point (Z) located at x=0.75a, and y =0.25b, in time domain response is plotted in Fig. 8.

4.1 Modelling Using Adaptive Neuro-Fuzzy Inference System

A MATLAB coding has been produced based on the ANFIS Networks. Since there was not a priori knowledge about a suitable order of the model for the flexible plate system, the structure realization was performed by a trial-and-error method. So, the deflection model was observed with different orders. The data set, comprising 4000 data points, was divided into two sets of 3000 and 1000 data points respectively. The first set was used to train the network and the second set was used to validate the model. The best result was achieved with model order = 4, which means, $n_u = n_y = 2$ for 3000 data length was trained to characterize the plate. The model reached a sum-squared error level of 0.0003978 with 150 training passes for ANFIS network modelling. Fig. 9 and Fig. 10 present ANFIS Initial and final membership functions of the input variable, respectively. The model has 16 rules for model order n= 4 and 2 Gaussian membership functions. Gaussian membership functions with product inference rule are applied at the fuzzification level. The fuzzifier outputs the firing strengths for each rule. At the defuzzification level, the first order sugeno model is utilized. Fig. 11 shows the result of the actual and ANFIS predicted output, Fig. 12 shows error between actual and predicted ANFIS output. The division between the trained data and the unseen data is indicated as a vertical line located at point 3000 as shown in Fig. 11 and Fig. 12.

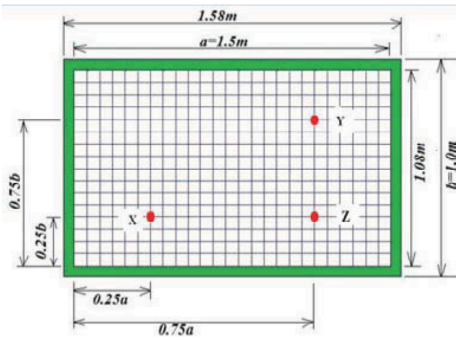

Fig. 6: Schematic of the plate with all edges clamped boundary conditions for the development of AVC

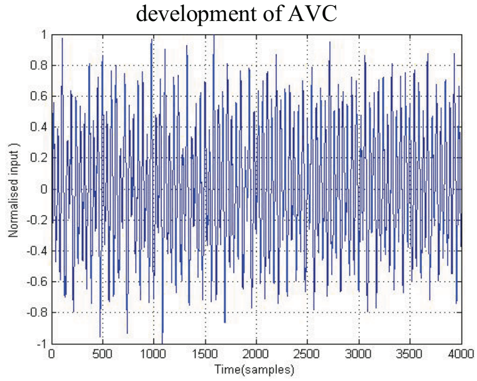

Fig. 7: Lateral deflection detected at x=0.75a, and y=0.75b point (Y)

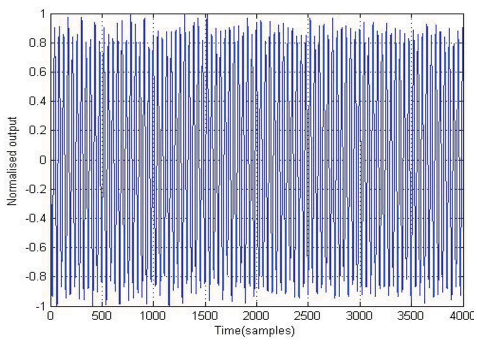

Fig. 8: Lateral deflection detected at x=0.75a, and y=0.25b point (Z)

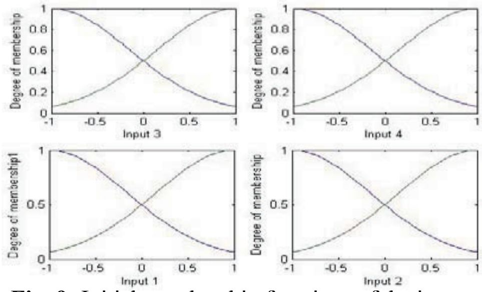

Fig. 9: Initial membership functions of the input variable

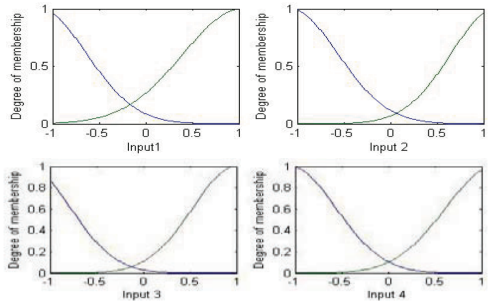

Fig. 10: Final membership functions of the input variable

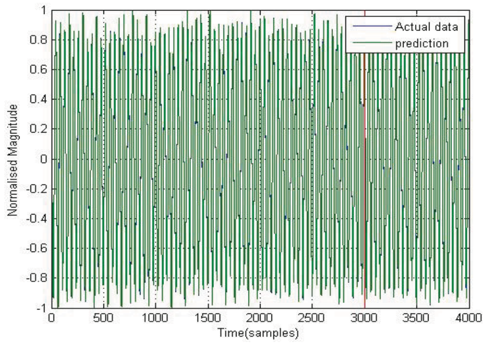

Fig. 11: Actual and ANFIS predicted output

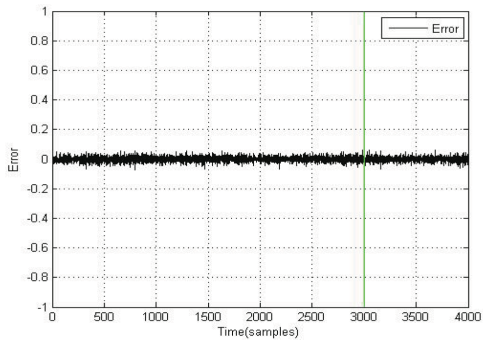

Fig. 12: Error between actual and predicted ANFIS output

Correlation tests were carried out to determine the effectiveness of the ANFIS-based model. Fig. 13 shows the results of the correlation tests. The results were also within 95% confidence level thus confirmed the accuracy of the results.

5. CONCLUSION

An ANFIS model characterizing a flexible plate structure has been presented and discussed. The best feature of ANFIS is that it pre-processes all the data into several membership functions before mapping the data into an adaptive neuro structure. This pre-processing feature allows ANFIS to converge faster and better .A dynamic model based on experimental study is developed at initial stage of the work. The ANFIS model has been evaluated and the ANFIS output is plotted against the actual output. ANFIS model has been shown to exhibit like the true system, with small errors developed between actual and predicted output. This model can be used to in future work to design vibration suppression mechanism on the flexible structure.

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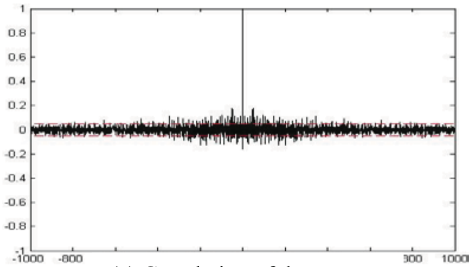
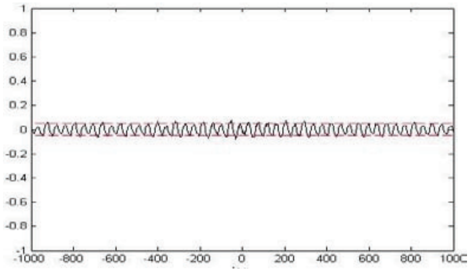
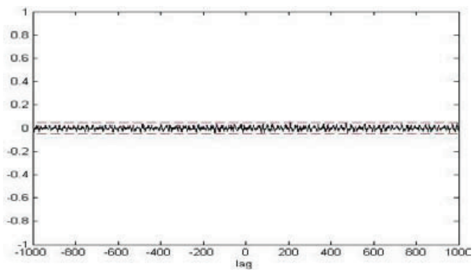


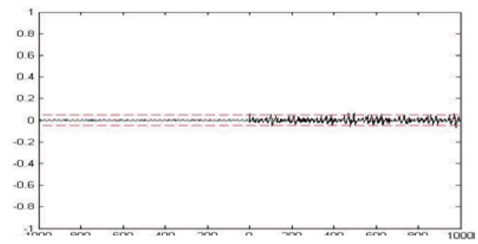
(a) Correlation of the error



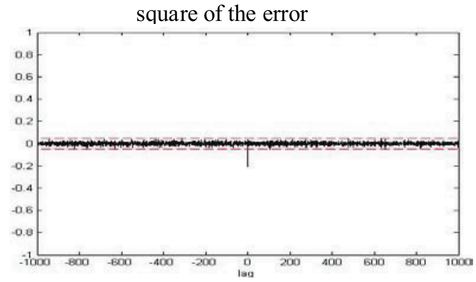
(b) Correlation of the input and the error



(c) Correlation of the square of input and the error



(d) Correlation of square of the input square of the error



(e) Correlation of multiplication of the input by the error and the error

Fig. 13: Correlation tests of ANFIS