THE VIBRATION CONTROL OF SMART STRUCTURE USING OBSERVER BASED ADAPTIVE NEURO FUZZY CONTROLLER

SRIDEVI MANI¹ & MADHAVASARMA PASUPATHY²

¹Associate Professor, Department of Electrical and Electronics Engineering, Veltech Multitech

Dr. Rangarajan & Dr. Sakunthala Engineering College, Avadi Chennai, Tamil Nadu, India

²Professor, Department of Electronics and Communication Engineering, Saraswathy

College of Engineering and Technology, Tamil Nadu, India

ABSTRACT

This paper deals with vibration control for a cantilever beam using observer based Adaptive Neuro Fuzzy Inference System. Cantilever beam model replicates the aircraft wing structure exhibiting non linear characteristics. The cantilever has piezoelectric patches surface bonded on it which acts both as sensor and actuator. The strain and strain rate are the state variables observed and controlled to suppress the vibration. System identification was done using an ARMAX parameterized approach technique. For the Identified model Adaptive Neuro Fuzzy Inference System (ANFIS) was designed as an Observer. The Observer performances were evaluated using MATLAB simulation. The percentage suppression of vibration varied from 75% to 99% for observer based state feedback controller and Adaptive Neuro Fuzzy Controller respectively.

KEYWORDS: Cantilever, Adaptive Neuro Fuzzy Inference System, Observer, ARMAX & Nonlinear

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INTRODUCTION

Recently with advancement in physics towards micro and nano technologies there is a rapid growth in number of variety of applications of Artificial intelligence in material sciences, robotics, aircraft and light weight systems. Nowadays for solving real world modelling and control problems hybrid intelligent systems (Neuro-Fuzzy) is needed due to increase in complexity of process control problems. Hybrid intelligent systems have the ability to incorporate human based thinking, reasoning, self-sustainability and adapt to change in uncertainty via prior training. Smart structures have self-sensing action and reaction capabilities and piezo electric materials by their nature act both as sensor and actuator. Many materials and technologies have been proposed by different researchers. Chopra [1] for sensing and actuation used piezoelectric materials. Costain et al [2] innovated various useful real time methods for the control of vibration for industrial equipments. Various authors have discussed about model design of using smart structure having piezoelectric material as sensor/actuator [3-6]. Choi et al [7-8] performed position tracking control of a smart flexible structure featuring a piezofilm actuator, artificial intelligent techniques for piezoelectric bonded structures. Hanagud et al [9-10] have designed controller using optimization techniques. Sridevi et al [11-13] has designed and implemented state estimation algorithm and output feedback based controller for smart structure. Madhavasarma et al [13-16] have developed a measurement setup for nonlinear process and have designed intelligent control system. Radhakrishnan et al [17] have designed a modified recurrent Elman network using back propagation through time algorithm (BPTT) for

nonlinear plants. The present work aims at the design of observer based Adaptive Neuro Fuzzy Inference System (ANFIS) Controller to suppress the primary (first) vibration mode of a smart cantilever beam using MATLAB software.

EXPERIMENTAL SETUP

The experimental set-up for smart structure control explained briefly at [20] is shown in Figure 1.

Figure 1: Experimental Setup for Smart Structure Control

MODEL IDENTIFICATION

Revolution in the electronics industry has resulted in increase in usage of online identification and control for which accurate modelling is essential. Various modelling techniques briefly discussed in [13]. The state space model of the identified system through ARMAX converted into the continuous domain from discrete domain is given below.

$$A = \begin{bmatrix} -1350 & -480300 \\ 1 & 0 \end{bmatrix}; B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}; C = [0.002 \quad -0.1313]; D = [0]$$

DESIGN OF FULL ORDER OBSERVER

A Full order observer based state feedback controller was designed to observe the state variables of the smart structure namely strain and strain rate. Here the observer is selected as it eliminates the practical measurement of states and reduces the cost of the sensors. Observer estimates the actual plant and the state variables. The observer gain matrix corresponds to the correction term involving the difference between actual and estimated output. The pole placement in any controller plays the major role in the stability of the system. Hence, here the observer poles are made two to five times faster than the controller poles to make observational error converge to zero quickly. Else if the sensor noise is considerable then the observer poles are twice to five times slower than the controller poles to reduce the bandwidth and lower the noise. The cantilever beam system was tested with sinusoidal signal resonant frequency 192 Hz and amplitude 1, 8, 20 and 490 volts. The observer gain was used as a state feedback gain and observer based state feedback controller was designed. The open loop and closed loop responses for the cantilever beam was shown in Figures 2 to 5.

Figure 2: Open Loop and Closed Loop Responses with Observer Based State Feedback for $1\sin 192t$

Figure 3: Open Loop and Closed Loop Responses with Observer Based State Feedback for $8\sin 192t$

Figure 4: Open Loop and Closed Loop Responses with Observer Based State Feedback for $20\sin 192t$

Figure 5: Open Loop and Closed Loop Responses with Observer Based State Feedback for $490\sin 192t$

DESIGN OF OBSERVER BASED ADAPTIVE NEURO FUZZY CONTROL

In the design of Fuzzy Inference System selection of type and number of Membership Functions (MF) plays a vital role as it decides fuzzy rules. Here for design of Adaptive Neuro-Fuzzy Controller Gaussian MF was used to create a Radial basis Functional network. For Framing Fuzzy rules Grid partition technique was applied as the state variables to be controlled are strain and strain rate. Moreover as the problem of curse of dimensionality did not raise grid partitioning was applied to train the adaptive neuro-fuzzy controller. The output from Full observer based state feedback controller was acting as reference/training data to train the network. FIS Rule based structure generated using the grid partition technique was trained using a combination of back propagation and gradient descent algorithms was shown in Figure 6. The training epoch was 30. The Adaptive Neuro-Fuzzy Controller output for the input voltages 1V, 8V, 20V, 490V and resonant frequency 192Hz are shown in Figures 7 to 10 respectively. The Training errors are shown in Figures 7 to 10 respectively. The training error varied from 0.019, 0.15, 0.38, and 9.42.

Figure 6: Adaptive Neuro-Fuzzy Controller Structure Generated Using the Grid Partition Technique

Figure 7: Adaptive Neuro-Fuzzy Inference System Output Generated for $1\sin 192t$

Figure 8: Adaptive Neuro-Fuzzy Inference System Output Generated for 8sin192t

Figure 9: Adaptive Neuro-Fuzzy Inference System Output Generated for 20sin192t

Figure 10: Adaptive Neuro-Fuzzy Inference System Output Generated for 490sin192t

Figure 11: Adaptive Neuro-Fuzzy Controller Training Error 0.019 for 1sin192t

Figure 12: Adaptive Neuro-Fuzzy Controller Training Error 0.15 for 8sin192t

Figure 13: Adaptive Neuro-Fuzzy Controller Training Error 0.38 for 8sin192t

Figure 14: Adaptive Neuro-Fuzzy Controller Training Error 9.42 for 490sin192t

RESULTS AND DISCUSSIONS

The ARMAX model for the piezoelectric bonded beam was simulated using MATLAB software. The open loop and closed loop responses for the cantilever beam system was tested with resonant frequency 192 Hz and amplitude 1, 8, 20 and 490 volts was shown in Figures 15 to 18. The amplitude of vibration was reduced to approximately 26V with Full order observer based state feedback control and 10V with Adaptive Neuro-Fuzzy Controller. It was also observed that the settling time for Adaptive Neuro-Fuzzy Controller varied from 150 seconds to 300 seconds for the given input frequencies.

Figure 15: Open Loop and Closed Loop Responses with Observer Based Adaptive Neuro Fuzzy Controller for 1sin192t

Figure 16: Open Loop and Closed Loop Responses with Observer Based Adaptive Neuro Fuzzy Controller for 8sin192t

Figure 17: Open Loop and Closed Loop Responses with Observer Based Adaptive Neuro Fuzzy Controller for 20sin192t

Figure 18: Open Loop and Closed Loop Responses with Observer Based Adaptive Neuro Fuzzy Controller for $490\sin 192t$

Table 1: Performance Comparison of the Controllers

S. No	Controller	Input Voltage (Volt)	Input Frequency (Hz)	Output Amplitude (Volts)		Vibration Suppression (%)
				Open Loop	Closed Loop	
1.	Observer based state feedback	1	192	0.4	0.12	75
2.		8	192	3.6	1	72
3.		20	192	8	2.4	70
4.		490	192	190	60	68.4
6.	Adaptive Neuro-Fuzzy	1	192	0.4	0.002	99
7.		8	192	3.6	0.2	94.4
8.		20	192	8	0.3	96
9.		490	192	190	20	89.5

CONCLUSIONS

To control the vibration of smart structure Observer based State feedback and Adaptive Neuro Fuzzy controller has been designed using an ARMAX model. The amplitude reduction in vibration observed was 75% with observer based state feedback controller and 99% with Neuro-Fuzzy controller. From the Table 1 it was observed that maximum suppression of the vibration is achieved using an Adaptive Neuro Fuzzy controller and it is best suited for vibration control of a cantilever beam.

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