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EXPERIMENTAL STUDY ON ACTIVE VIBRATION CONTROL OF A PIEZO-BEAM STRUCTURE WITH FUZZY LOGIC CONTROLLER

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ABSTRACT

In this study, it has been shown that active vibration control of the beam can be provided using the fuzzy logic controller. The test setup consists of a cantilever beam which illustrates a wing of airplane or a blade of helicopter, piezoelectric patches pasted on both sides near the fixed end in order to make the beam smart. This piezo-beam system is intended to be suppressed a disturbing signal at the first resonance frequency by the controller signal. As a controller, fuzzy logic controller is preferred instead of conventional ones. It is shown through the simulated and the experimental result that the vibration given to the system has been damped with fuzzy logic controllers developed by taking advantage of experience and references.

INTRODUCTION

Light damping structures in aerospace vehicles such as wings, blades etc. are exposed to severe vibrations resulting in heavy damage or fraction. Passive damping methods are not suitable for this type of construction due to weight limitation. The research also shows that passive control is not effective in damping vibrations in low frequency mode [Brooks, L., Moreau, D., Hansen, C., Qiu, X., & Snyder, S., 2012]. On the other hand, an active vibration control provides effective performance at low frequencies and programmable flexibility in controller design.

Piezoelectric patches are widely used in active vibration control system due to lightness, smallness and cost-effective. Additionally, these materials are used both as an actuator and a sensor in the system as they can convert mechanical movements to electrical signals and vice versa.

In Department of Aerospace Engineering, METU, Sahin el al. [Sahin, M., Karadal, F. M., Yaman, Y., Kircali, O. F., Nalbantoglu V., Ulker, F. D., and Caliskan, T., 2008] have developed research studies on the applications of smart structures with various control methods to provide more effective suppression of vibrations using the piezoelectric patches as sensors and actuators. C. Onat, M. Sahin, and Y. Yaman have developed PIλDμ and fractional-level controller and Luenberger observer on smart beam.

Fuzzy logic control can also be part of the active control mechanism as a controller. Fuzzy logic controller works based on human decision making process [Chen, G. & Zhou, L., 2015]. Fuzzy logic controller design can be done with trial and error and experience without knowing the mathematical model of the plant. Lin, J. et al. [Lin, J. and Liu, WZ, 2006] experimentally demonstrated the superiority of the fuzzy logic controller to the classical PD controller.

In this study, suppression of the first resonance vibration of a smart beam with fuzzy logic controller is performed with comparing the simulated results with the experimental ones.

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METHOD

Experimental Setup

Four pieces of piezoelectric patches are glued to fix end of the cantilever beam with 35 cm length, 3 cm width and 2 mm thickness (Figure 1). Two of them are the controller PZT patches, one is the sensor PZT patch, and the other one is the disturbance PZT patch.

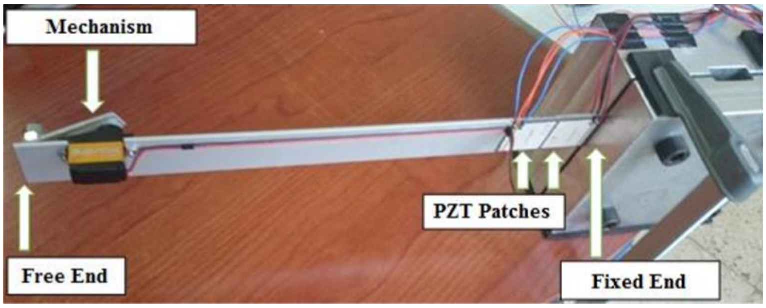


Figure 1: Smart Beam [Akın, O. & Sahin, M., 2015]

Controller PZT patches are glued symmetrically the front and back surfaces of the beam as shown in Figure 2; thus, electrical connection is made in order to increase the effect bimorph configuration. The sensor PZT patches, which measure the vibration on the beam, and the disturbing PZT patches, which act as the vibration source to the beam, are glued as shown.

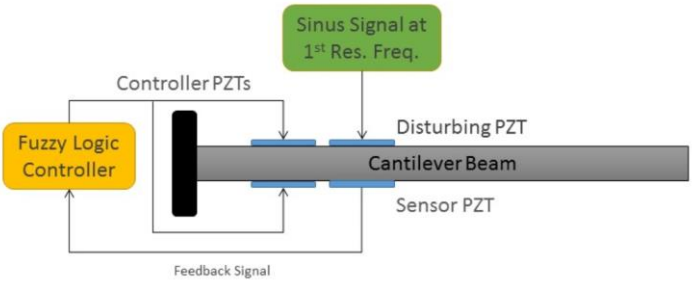


Figure 2: Schematic Representation of the Test Setup

At the free end of the beam, a servo mechanism is placed which can change the transfer function of the system with the position of the weight. In this study, however, the weight position keep constant.

System Identification

Frequency response function (FRF) of the beam is obtained by using signal between controller and sensor PZT patch. Signal data on sensor PZT patch are gathered while controller PZT patches on the beam is being excited with logarithmic swept-frequency with initial frequency 1 Hz and target frequency 40 Hz as shown in Figure 3.

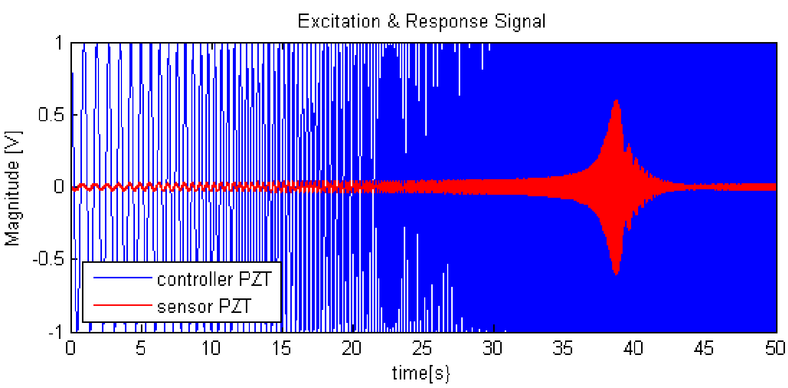


Figure 3: Excitation and Response Signal

The measured time domain data is processed at System Identification Toolbox on Matlab. Transfer functions (1) between controller and sensor PZT patches are obtained with 97% best fit. Also, FRF curve is plotted in Figure 4 and first natural frequencies are calculated from this FRF as 14.51 Hz.

$$G(s) = \frac{0.1629s^3 + 0.3735s^2 + 1415s + 933.7}{s^3 + 19.63s^2 + 8339s + 1.49710^5} \quad (1)$$

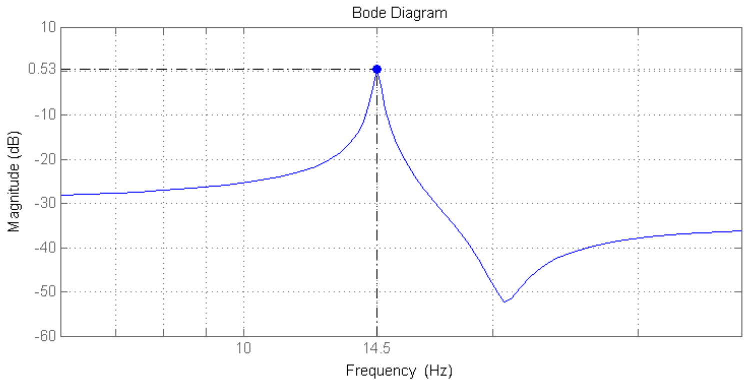


Figure 4: Bode Diagram of the Estimated Transfer Function

Fuzzy Logic Controller Design

In this study, a fuzzy logic controller is designed according to the estimated model in order to suppress the disturbance excitations at the first natural frequency of the smart beam. The fuzzy logic controller is built via Fuzzy Logic Toolbox of MATLAB.

Algorithm of the fuzzy system takes the error and error change as input signal and calculates the control signal at the output (Figure 5**Hata! Başvuru kaynağı bulunamadı.**). This system consist of 3 step; fuzzification, fuzzy rule and defuzzification.

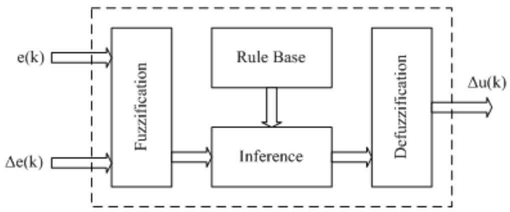


Figure 5: Schematic Representation of Fuzzy Logic System [Akyazi, O., Usta, M. A., & Akpinar A. S., 2012]

First, five fuzzy set have been specified in order to define the magnitude of error, error change and controller output voltage in linguistic term which are negative big [NB], negative small [NS], zero [ZE], positive small [PS] and positive big [PB].

In the fuzzification step, five membership functions have been defined for each inputs and output. The functions are fuzzified the input data and give a value between 0 and 1 for each fuzzy set. Membership functions of inputs and output variables are shown in Figure 6. For example; in Figure 6, take value of error as -0.15 volt and NS will be 0.75, ZE will be 0.25 and NB, PS and PB will be 0. Error value of -0.15 has meant 75% negative small or 25% zero in linguistic terms. Membership functions and limits are based on experience gained through countless experiments.

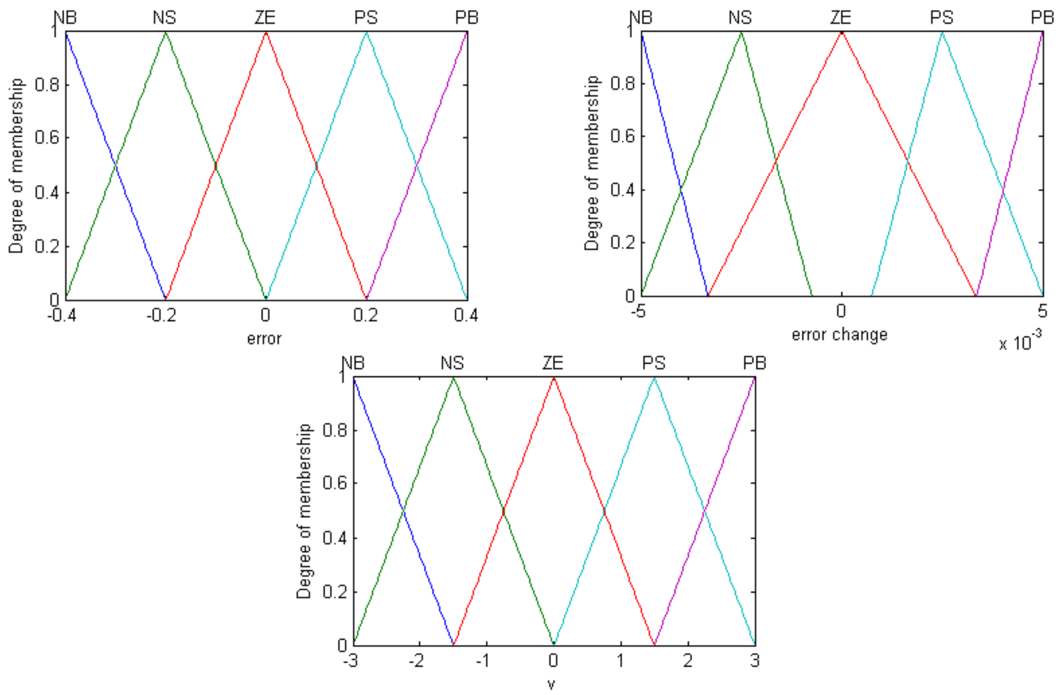


Figure 6: Membership Functions of Input and Output Variables

In fuzzy logic, rules are formulated with conditional states such as “if .., then ..” statements. The rule base (Table 1) was created entirely analogous to the human decision making process. For example; in Table 1, if error is NS and error change is PS, then output will be ZE.

Table 1: Fuzzy Logic Rule Table

error	*error change*				
	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	NS
NS	NS	NS	NS	ZE	ZE
ZE	NS	NS	ZE	PS	PS
PS	ZE	ZE	PS	PS	PS
PB	PS	PS	PB	PB	PB

In defuzzification, the fuzzy set obtained from the rules is converted into finite value of the output. The surface graphics of the controller output are shown in Figure 7 based on the error and error change inputs.

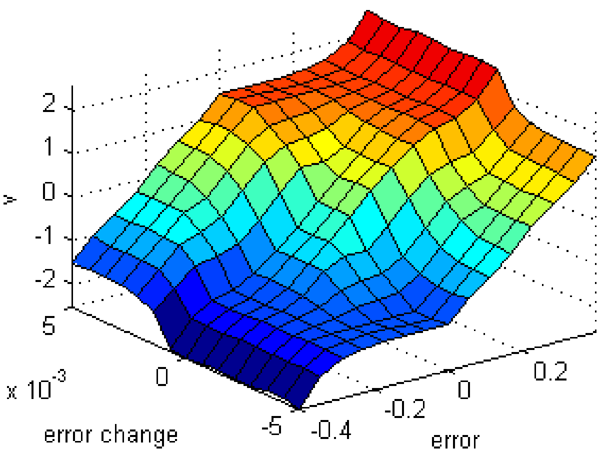
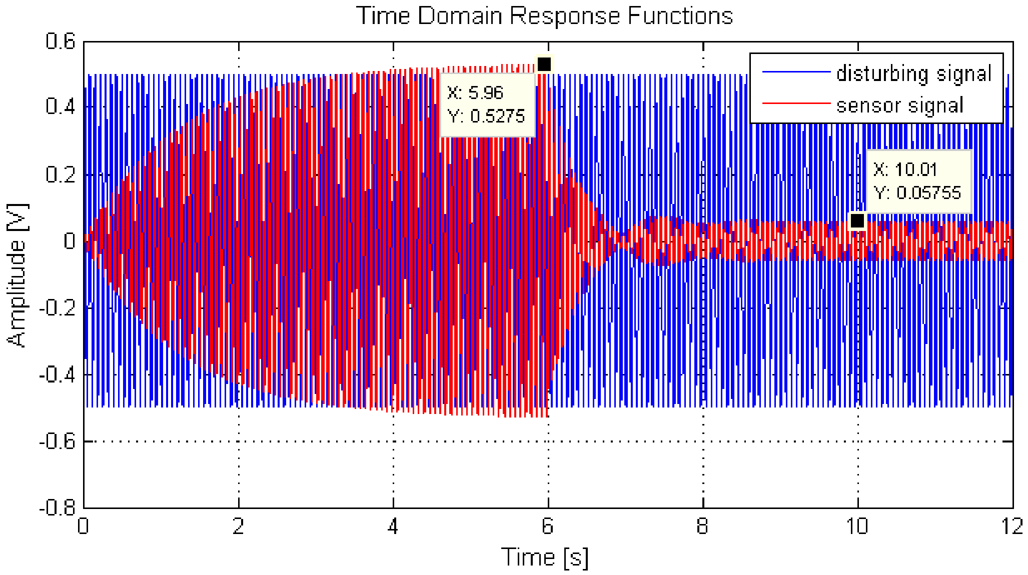


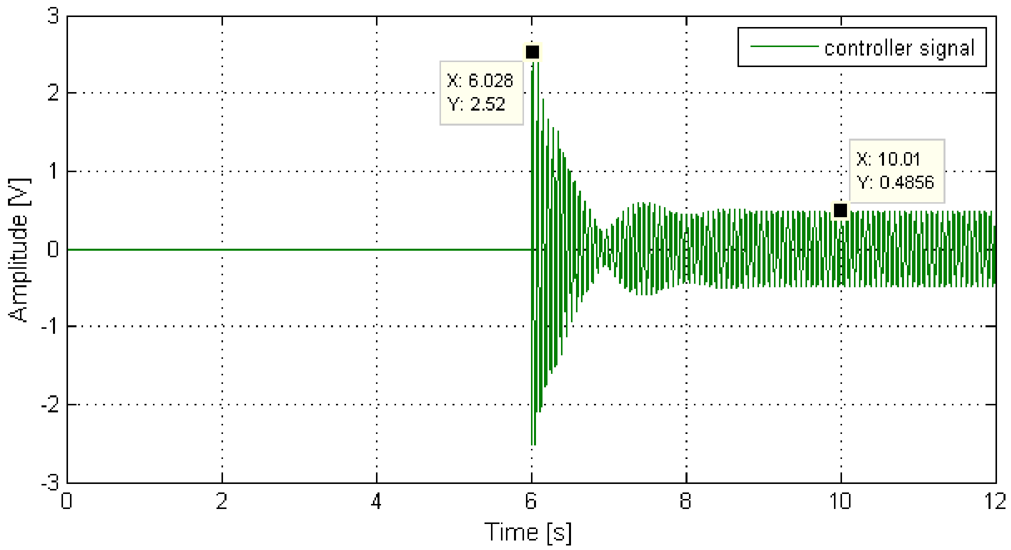
Figure 7: Surface Graph

SIMULATION RESULTS

The damping of the smart beam whose transfer function is known and vibrating at its first natural frequency has being simulated. The system was started to vibrate with this sinusoidal at 14.51 Hz with 0.5-volt amplitude via controller PZT patch as disturbing signal. 5 seconds after the simulation start, the value of the sensor PZT patch reached 0.5275-volt amplitude and the system reached steady state as shown in Figure 8 (a).



(a) Distubing and Sensor Signal



(b) Controller Signal

Figure 8: The Simulation Results

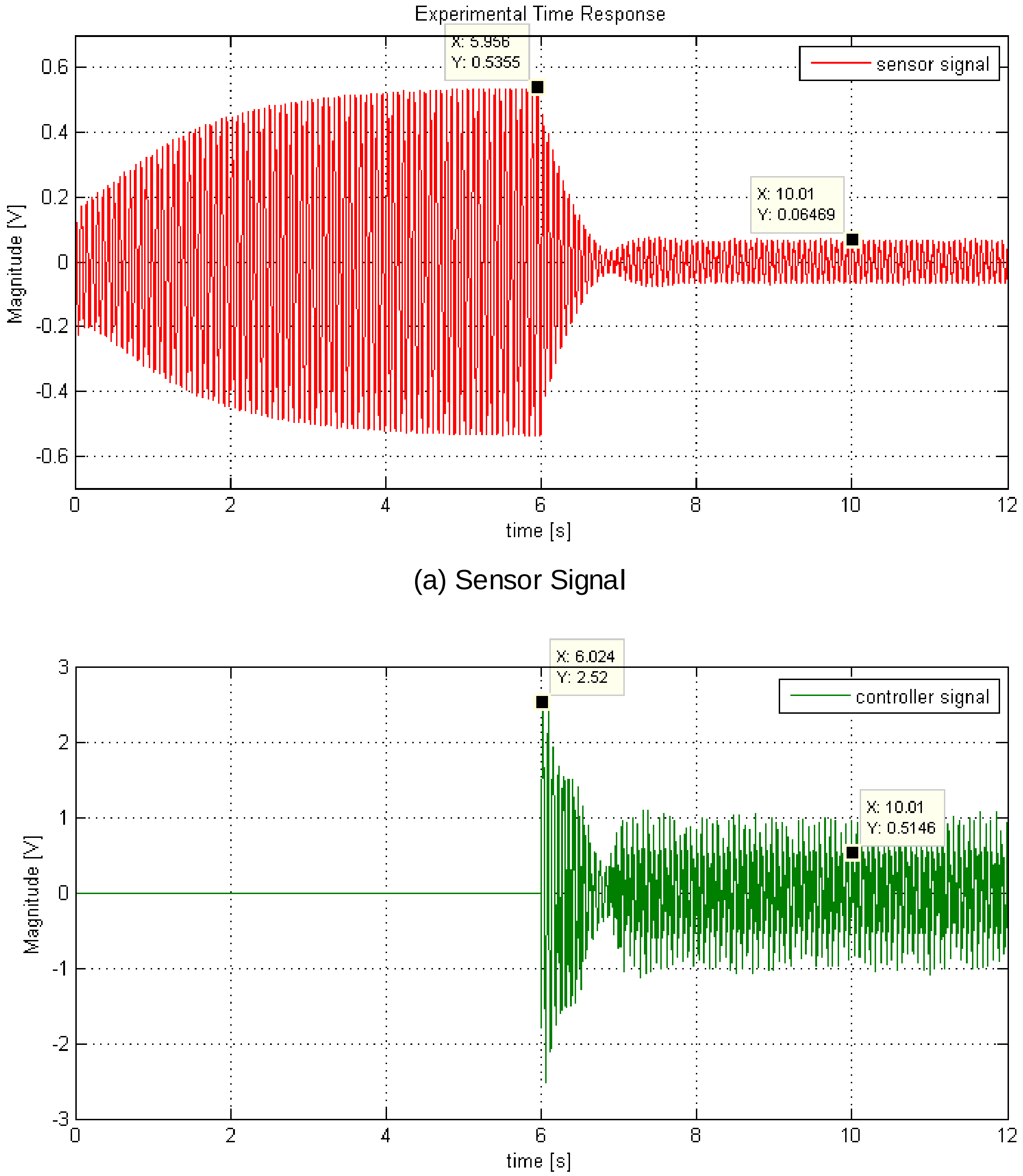
At the sixth second, the fuzzy logic controller signal is added the input signal which is disturbing signal in order to suppress the vibration. Then, the amplitude of sensor signal reduces to 0.05755 volt from 0.5275 volt in about one second (Figure 8 (a)). It shows that the forced vibration suppression ratio of the smart beam is 89% according to simulation results.

Additionally, in the transient region, which is in between the sixth and the eighth seconds, the maximum controller signal is around 2.5 volts which is about 5 times of the vibrating amplitude (Figure 8 (b)). On the other hand, the stable region of forced vibration starts after the eighth second. In the stable region, the maximum controller signal is 0.48 volt which is almost equal to the amplitude of vibration without controller.

EXPERIMENTAL RESULTS

In the experiment, disturbing PZT patch excites the beam at the resonant frequency and the signal of sensor PZT patch in (b) Controller Signal

Figure 9 (a) shows that the vibration is stable at the fifth second and the amplitude of the voltage reaches to 0.5355 volt.



(a) Sensor Signal

(b) Controller Signal

Figure 9: Experimental Result

Controller PZT patches are activated after the sixth second. In one second, fuzzy logic controller reduces the amplitude of the sensor signal to 0.0647 volt which means the forced vibration suppression ratio of the smart beam is 88% according to the experimental results. The difference between the experimental and the simulation result is 1%.

Controller PZT patches produce maximum voltage at the beginning of the suppression as 2.52 volt which is exactly the same as the simulation result. Moreover, in the stable region, the amplitude of the controller signal is 0.5146 volt which is also close to the controller signal in the simulation. However, there are some peak values about 1 volt during the stable region of forced vibration where the time is after seventh second in Figure 9 (b). The reason of this should be the high frequency noise and saturation.

CONCLUSION

In this study, the vibration suppression using the fuzzy logic controller at the first resonant frequency of the smart beam is shown by comparing the simulation and experimental results. The experimental and simulation results are obtained with error percentage of 1%. Additionally, the performance of the controller has been achieved with an effective damping ratio of 88%.

In the future, an adaptive fuzzy logic controller can be designed which is not affected by the changes in the system parameters. Therefore, the performance of an adaptive fuzzy logic controller can be observed by changing the position of the mass at the tip of the beam.

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