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Intelligent Active Vibration Control for a Flexible Beam System

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Abstract - *This paper presents an investigation into the development of an intelligent active vibration control (AVC) system. Evolutionary Genetic algorithms (GAs) and Adaptive Neuro-Fuzzy Inference system (ANFIS) algorithms are used to develop mechanisms of an AVC system, where the controller is designed on the basis of optimal vibration suppression using the plant model. A simulation platform of a flexible beam system in transverse vibration using finite difference (FD) method is considered to demonstrate the capabilities of the AVC system using GAs and ANFIS. MATLAB GA tool box for GAs and Fuzzy Logic tool box for ANFIS function are used for AVC system design. The system is then implemented, tested and its performance assessed for GAs and ANFIS based design. Finally a comparative performance of the algorithm in implementing AVC system using GAs and ANFIS is presented and discussed through a set of experiments.*

Keywords: Active vibration control, intelligent algorithm, system identification, Genetic algorithms, ANFIS.

1 Introduction

This research investigates into the design and development of an intelligent active vibration control system. Many attempts have been made in the past at devising methods of tackling the problems arising due to unwanted structural vibrations (disturbances) consist of passive and active control. Traditional methods of vibration suppression include passive control, which consist of mounting passive material on the structure. On the other hand, AVC consists of artificially generating cancelling source(s) to destructively interfere with the unwanted source and thus result in a reduction in the level of the vibration (disturbances) at desired location(s). This is realised by detecting and processing the vibration by a suitable electronic controller so that, when superimposed on the disturbances, cancellation occurs. Due to the broadband nature of the disturbances, it is required that the control mechanism in an AVC system realises suitable frequency-dependent characteristics so that cancellation over a broad range of frequencies is achieved. In practice, the spectral contents of the disturbances as well as the characteristics of system components are, in general, subject to variation, giving rise to time-varying phenomena. This implies that the control mechanism is further required to be intelligent enough to track these variations so that the desired level of performance is achieved and maintained [1], [2].

A flexible beam system in transverse vibration is considered in this paper. Such as system has an infinite number of modes, although in most cases the lower modes are the dominant ones requiring attention. The unwanted vibrations in the structure are assumed to be the result of a single point disturbance of broadband nature. First-order central finite difference (FD) methods are used to study the behaviour of the beam and develop as suitable test and verification platform. An AVC system is designed utilising a single input single output control structure to yield optimum cancellation of broadband vibration at a set of observation points along the beam. The controller design relations are formulated such as to allow on-line design and implementation and thus, yield an adaptive control algorithm [3].

It is reported earlier that the conventional on-line system identification schemes are in essence local search techniques [4]. These techniques often fail in the search for the global optimum if the search apace is not differentiable or linear in the parameters. To overcome this limitation, this investigation employed GAs and ANFIS to identify characteristics of the AVC system.

The evolutionary GAs and the ANFIS algorithm of the MATLAB tool boxes are used to estimate the controller characteristics, where the controller is designed based on the plant model. This is realised by minimising the prediction error of the actual plant output and the model output. The flexible beam system mentioned above is considered as the plant model. An AVC system is designed for optimum cancellation of broadband vibration along the beam. The AVC algorithm is designed, implemented and tested using GAs and ANFIS algorithm. The performances of the both algorithms in implementing AVC system are assessed in the suppression of vibration along the beam. These are presented and discussed through a set of experiments.

2 Algorithms

The intelligent active vibration control algorithm consists of flexible beam simulation algorithm, control algorithm and system identification using GAs and ANFIS. These are briefly described below.

2.1 Simulation and Control Algorithms

Consider a cantilever beam system with a force $F(x,t)$ applied at a distance x from its fixed (clamped) end at time t. This will result in a deflection $y(x,t)$ of the beam from its stationary position at the point where the force has been applied. In this manner, the governing dynamic equation of the beam is given by

$$\mu^2 \frac{\partial^4 y(x,t)}{\partial x^4} + \frac{\partial^2 y(x,t)}{\partial t^2} = \frac{1}{m} F(x,t) \qquad (1)$$

where, μ is a beam constant and m is the mass of the beam. Discretising the beam into a finite number of sections (segments) of length Δx and considering the deflection of each section at time steps Δt using the central finite difference (FD) method, a discrete approximation to equation (1) can be obtained as [5]

$$Y_{k+1} = -Y_{k-1} - \lambda^2 S Y_k + \frac{(\Delta t)^2}{m} F(x,t) \qquad (2)$$

where, $\lambda^2 = \mu^2 (\Delta t)^2 / (\Delta x)^4$, S is a pentadiagonal matrix, entries of which depend on the physical properties and boundary conditions of the beam, and Y_i ($i = k+1, k, k-1$) is a vector representing the deflection of end of sections 1 to n of the beam at time step i. Equation (2) is the required relation for the simulation algorithm.

A schematic diagram of an AVC structure is shown in Figure 1. A single-input single-output active vibration control system is considered for vibration suppression of the beam. The unwanted (primary) disturbance is detected by a detection sensor, processed by a controller to generate a cancelling (secondary, control) signal so as to achieve cancellation at an observation point along the beam. The objective in Figure 1 is to achieve total (optimum) vibration suppression at the observation point. This requires the primary and secondary signals at the observation point to be equal in amplitudes and to have a 180° phase difference. Synthesising the controller on the basis of this objective will yield the required controller transfer function as [2], [4].

$$C = \left[1 - Q_1/Q_0\right]^{-1} \qquad (3)$$

where Q_0 and Q_1 represent the equivalent transfer functions of the system (with input at the detector and output at the observer) when the secondary source is *off* and *on* respectively. Equation (3) is the required controller design rule which can easily be implemented on-line. This will involve estimating Q_0 and Q_1, using a suitable system-identification algorithm, designing the controller using equation (3) and implementing the controller to generate the control signal. In this investigation, the evolutionary GAs and ANFIS algorithms are used as system identification algorithms to estimate the controller parameters of the AVC system. The methodologies of using these two algorithms are briefly described below.

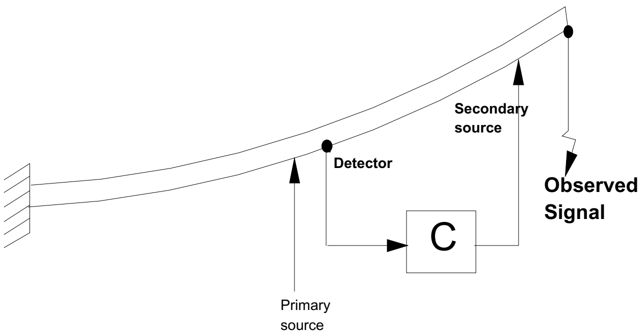

Figure 1. Active vibration control structure

2.2 Genetic Algorithms

The conventional on-line system identification schemes such as least squares, instrument variable, maximum likelihood etc., are in essence local search techniques. These techniques often fail in the search for the global optimum if the search space is not differentiable or linear in the parameters. On the other hand these techniques do not iterate more than once on each datum received. In contrast, GAs are the algorithms for simultaneously evaluates many points in the parameter space and converges towards the global solution. This algorithm differs from other search techniques by the use of concepts taken from natural genetics and evolution theory. The genetic algorithm is used based on the method of minimization of the prediction error [4]. The method of evolutionary computation works as follows: create a population of individuals, evaluate their fitness, generate a new population by applying genetic operators, and repeat this process for a number of times. GAs consider the same multi parameter system given by equation (2) then defined the following fitness function.

$$f(e) = \sum_{k=1}^{r} \left| y(k) - \hat{y}(k) \right| \quad (4)$$

where, $y(k)$ is measured output, $\hat{y}(k)$ is estimated model output, and r is the number of sets of measurement considered. Equation (4) may be written in vector form as:

$$f(e) = \sum_{k=1}^{r} \left| y(k) - \hat{\theta}_0 \hat{\psi}(k) \right| \quad (5)$$

2.3 Adaptive Neuro-Fuzz Inference System

The MATLAB ANFIS algorithm provides a method for the fuzzy modelling procedure to learn information about a data set, in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input-output data. This learning method works similarly to that of neural networks. There is a MATLAB function in the Fuzzy Logic Toolbox that accomplishes this membership function parameter adjustment called ANFIS. This hybrid adaptive neuro-fuzzy function ANFIS is used for system identification which is the major training routine for Sugeno-type FIS (fuzzy inference systems). ANFIS has proven to be excellent function approximation tool [6], [7].

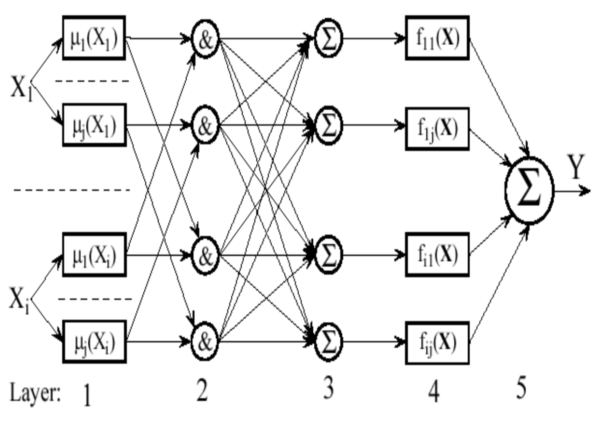

Figure 2. Basic ANFIS structure

Figure 1 shows the basic structure of the ANFIS algorithm for a first order Sugeno-style fuzzy system. It is worth noting that the Layer-1 consists of membership functions described by generalised bell function:

$$\mu(X) = (1 + ((X - c)/a)^{2b})^{-1} \quad (6)$$

where a, b and c are adaptable parameters. Layer-2 implemented the fuzzy AND operator, while Layer-3 acts to scale the firing strengths. The output of the Layer-4 is comprised of a linear combination of the inputs multiplied by the normalised firing strength w.

$$Y = w(pX + r) \quad (7)$$

where p and r are adaptable parameters. Layer-5 is simple summation of the outputs of layer-4. The adjustment of modifiable parameters is a two step process. First, information is propagated forward in the network until Layer-4, where the parameters are identified by a least-squares estimator. Then the parameters in Layer-2 are modified using gradient descent. The only user specified information is the number of membership functions in the universe of discourse for each input and output as training information.

3 Implementation and results

As mentioned earlier, a flexible beam system in transverse vibration of length L = 0.635 meter, mass m = 0.037 kg, was considered as plant for investigation. The beam was discretised into 19 small segments. To allow dominant modes of vibration of the beam to be excited, a step disturbance force (0.1N) of finite duration was applied to a suitable node of the beam. The input and output samples of the plant was collected from two suitable nodes of the beam. Moreover, sample period was selected as $\Delta t = 0.3$ ms which is sufficient to cover all the resonance modes of vibration of the beam [4].

Figure 3 shows the end point deflection of the beam before vibration suppression. Figures 4 and 5 are the corresponding deflections at the same point after cancellation using ANFIS and GAs, respectively. Figure 4 depicts the time domain performance in implementing the AVC system using ANFIS algorithm. In contrast Figure 5 depicts the time domain performance in implementing the AVC system using GAs. It is noted that ANFIS based control algorithm achieved significantly better performance between the two. It is also noted that the peak to peak amplitude before cancellation was +7mm to -7mm. It reduced to +1.8mm to -1.8mm by ANFIS based AVC system and +4mm to -4mm by GAs based AVC system.

This is further demonstrated in the Figures 6 and 7. In Figure 6, the solid line depicts the auto-power spectral density before cancellation and the doted line depicts the auto-power spectral density after cancellation in implementing the AVC system using ANFIS. In contrast, Figure 7 presents the performance of GAs based controller, where the solid line represents before cancellation and doted line represents after cancellation. It is noted that a significant level of reduction is achieved by ANFIS for the first resonant frequency. As compared to the GAs based AVC system, ANFIS based system offers about 4 times better performance at first resonant mode.

However, this level of vibration suppression is not consistent for the higher resonant modes. In contrast, the GAs based AVC system achieved relatively better performance at higher resonant modes.

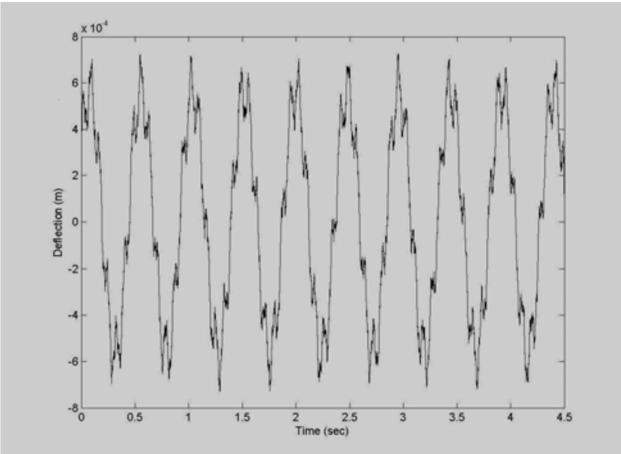

Figure 3. Beam fluctuation at the end point before cancellation

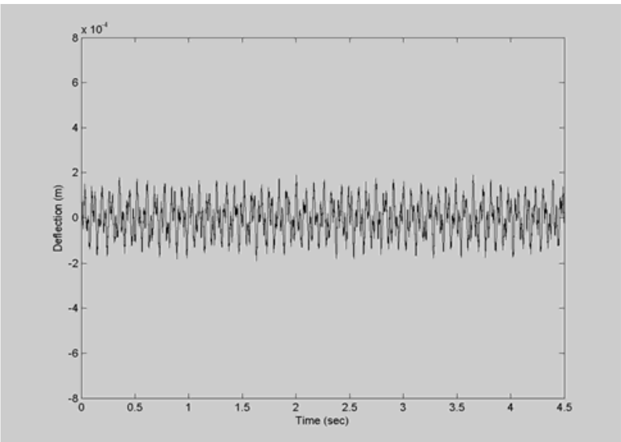

Figure 4. Beam fluctuation at the end point after cancellation in implementing AVC using ANFIS

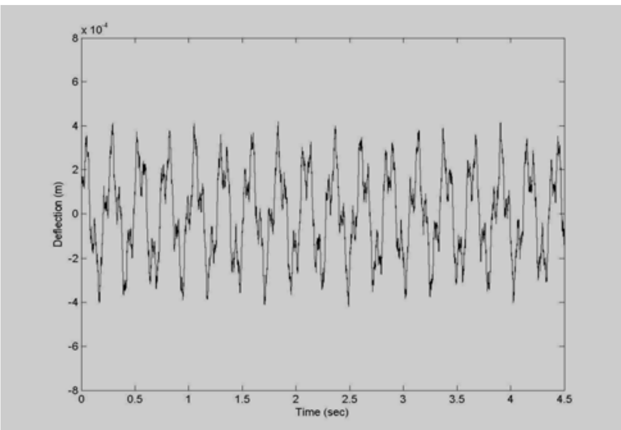

Figure 5. Beam fluctuation at the end point after cancellation in implementing the AVC system using GAs

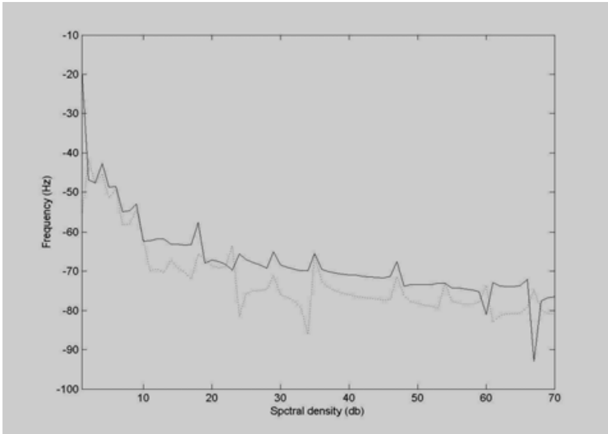

Figure 6. Auto-power spectral density at the end point (solid line represents before cancellation and doted line represents after cancellation in implementing the AVC system using ANFIS)

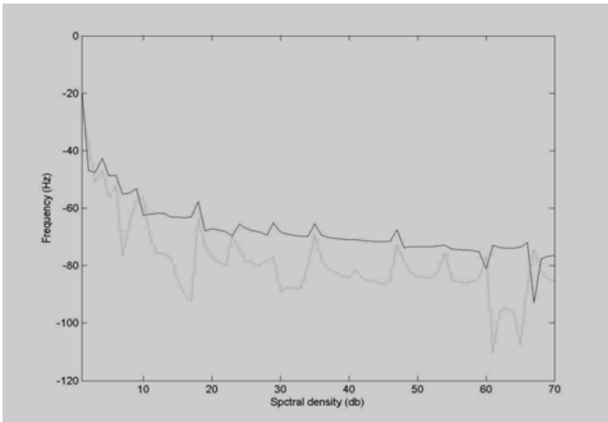

Figure 7: Auto-power spectral density at the end point (solid line represents before cancellation and doted line represents after cancellation in implementing the AVC using GAs)

4 Concluding Remarks

This paper has presented an investigation into the development of intelligent AVC algorithms using the evolutionary GAs and ANFIS for a flexible beam system in transverse vibration. MATLAB GA and Fuzzy Logic Tool boxes are used for GAs and ANFIS based AVC system design, respectively. The control algorithm has been implemented and verified to demonstrate the capabilities through a set of experiments. A comparative performance in implementing the AVC system using GAs and ANFIS has been presented and discussed. It is noted that a significant level of vibration cancellation has been achieved by ANFIS based AVC system at the lower resonant mode. However, GAs based AVC system shows relatively better performance at higher resonant modes.

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