Active Vibration Reduction: Genetic Algorithm Optimisation Using the Physical Structure

J M Hale
School of Mechanical and Systems Engineering, Newcastle University, Newcastle upon Tyne, UK
jack.hale@ncl.ac.uk

Introduction

The genetic algorithm (GA) has been used with some success for optimising active vibration reduction (AVR) of smart structures, both to find optimal locations for sensors and actuators [1] and optimal coefficients for control laws [2]. The obvious limitation of this technique is that the GA relies on a model of the system to provide values for the objective function to be minimised, and so the optimisation can be compromised by a poor model. This paper describes some work in which the physical system, rather than a simulation, is used to provide the data for the objective function.

Smart Structures with Active Vibration Reduction (AVR)

The conventional method for structural vibration reduction is passive high damping coatings. However, the added mass makes this unsuitable for low mass, high value structures such as satellites. The alternative is AVR, in which the naturally occurring vibration is "cancelled" by forcing the structure with vibration of appropriate frequency and phase. This is fairly straightforward for simple structures such as beams and plates, and when the vibration is exciting a single mode, but becomes difficult for even slightly more complex structures such as a stiffened plate, and when several vibration modes have to be controlled simultaneously.

Two aspects of this problem are addressed in this work: where to locate the sensors and actuators to measure the problem vibration and how to reduce it, respectively, and how to drive the actuators in response to the measured signals.

Genetic Algorithm with Hardware in the Loop

The genetic algorithm is a guided search optimisation techniques based on Darwinian natural selection. A breeding population is formed, each member of which is represented by a chromosome containing genes that code for a possible solution to the GA problem (in this case the locations of the sensors and actuators or the control coefficients). These solutions are tested against an objective function and the more successful ones "breed" to form the next generation. This process continues through many generations until convergence on an optimum is achieved. The technique is fully described in [3].

The GA is a computer technique and the objective function is normally evaluated using some kind of mathematical model, normally a finite element model for structural vibration applications. Since this has to be done for every member of the population (usually around 50) for every generation this can become very computationally intensive for large structures. It also suffers from the problem that the results will be invalid if the model is wrong, and this will not be obvious for large complex structures.

An alternative is to use the physical structure with sensors and actuators attached to provide data to evaluate the objective function directly. A simple structure is used here to test the viability of the technique. Two trials are presented: finding the optimal combination of a limited number of sensors and actuators to reduce multi-mode vibration, and finding optimal coefficients of a FIR filter network used to control the inputs to the actuators.

The structure used is shown schematically in Fig. 1. It comprises a cantilever beam with four accelerometer sensors and four electromagnetic shaker actuators. The sensors and actuators are collocated to prevent modal spill-over. A fifth shaker is used to provide the vibration to be reduced.

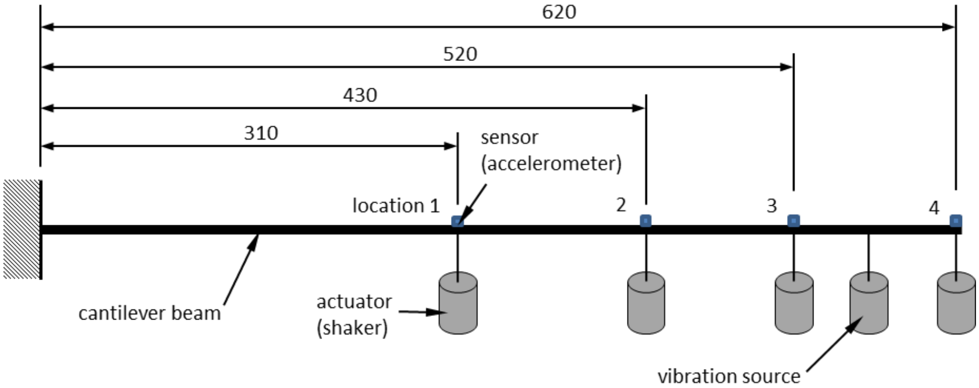

Fig. 1: Test Structure for Active Vibration Control

Controller Optimisation

The AVC system uses feedforward control by means of a FIR network filter with thirty tapped delay lines. The output $y(k) = \sum_{n=0}^{N-1} w_n x(k-n)$ where n is the nth of N delay lines, w_n is the weighting of the *n*th delay line, k is the sample number (discretised time) and x is the string of sampled input.

A simple example of the optimisation of the weighting coefficients is shown for a single sensor/actuator pair located at position 1 in Fig. 1. The GA was set up with a population of 30, each comprised of N+1 genes defining the filter weightings, initialised with random values. The beam was driven at 45.5Hz to excite the 2nd mode and the GA allowed to run. After some time the system converged and achieved a reduction of 11dB at the measuring sensor as shown in Fig. 2. This reduction was achieved without any *a priory* knowledge of the system.

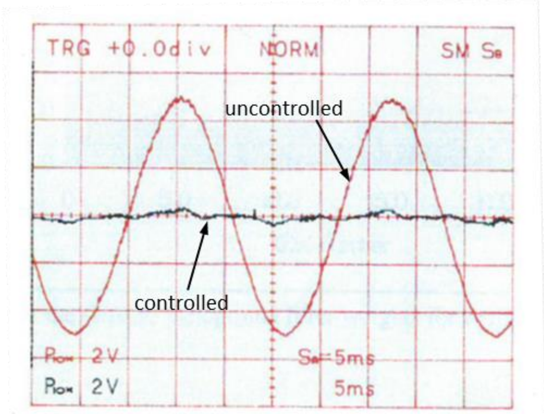

Fig. 2: Effect of active vibration control

Optimal Location of Sensor/Actuator Pairs

The beam was set with sensor/actuator pairs in all four locations in Fig.1. The genetic string was extended to combine sensor/actuator location and FIR filter weightings. The problem was expanded by driving the beam at 45.5Hz, 66.0Hz and 103.6Hz simultaneously to excite the 2nd, 3rd and 4th modes.

As before, a population of 30 was initialised randomly and allowed to run through 15 generations, after which it converged as shown in Fig. 3. This was a selection of the sensor/actuator at location 4, the beam tip, with FIR filter weightings giving attenuation of 34dB, 23dB and 26dB for the 2nd, 3rd and 4th modes as shown in Fig.4.

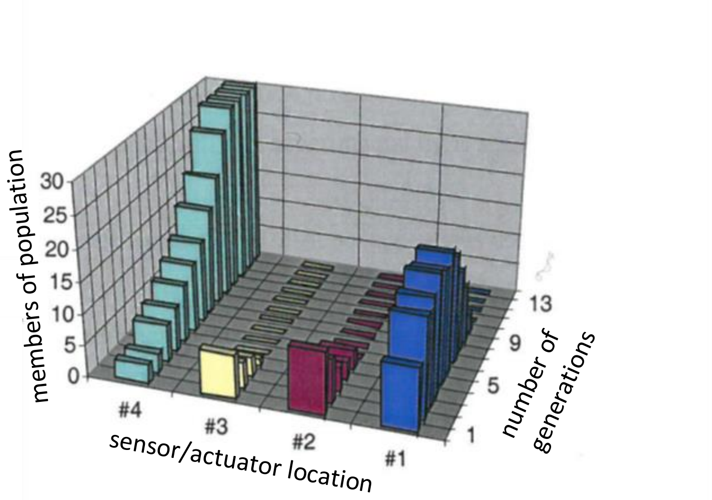

Fig. 3: Evolution of sensor/actuator location

Discussion

The results obtained show that the genetic algorithm can be used to determine optimum conditions for active vibration reduction, both location of sensors and actuators, and controller characteristics, without recourse to any mathematical models, either of the structure or the controller, by using the response of the physical structure to evaluate the objective function.

The result for the optimum location of the sensor/actuator pair on the cantilever beam is perhaps obvious, though the optimum FIR filter weightings for simultaneous control of three vibration modes are less so. The result could have been readily, and much more quickly, achieved using a model of the system. However, the same process could be applied to a much more complex structure for which the modelling would be more difficult and possibly unreliable, and the computation time for repeated runs of the model slower and more expensive.

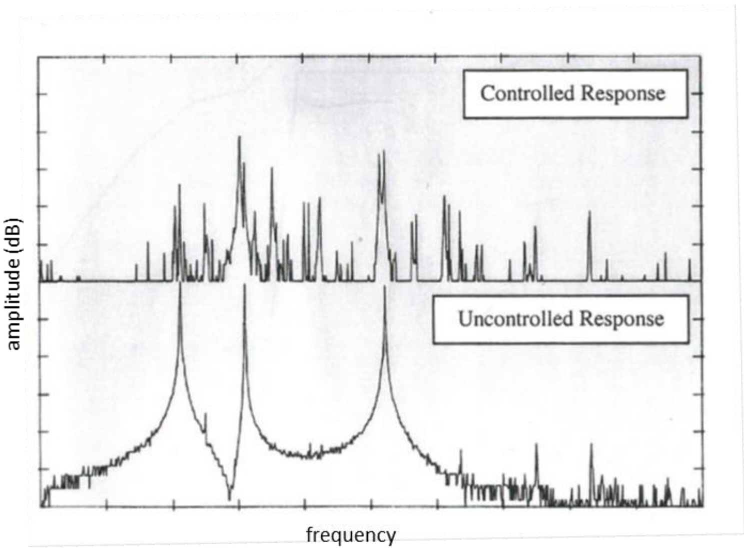

Fig. 4: Effect of active vibration control three modes simultaneously

References

[1] Ali Daraji and Jack Hale: *Active Vibration Reduction by Optimally Placed Sensors and Actuators with Application to Stiffened Plates by Beams,* Smart Materials and Structures, vol 23, no 11, 2014, on-line ref 115018,

[2] A H Daraji and J M Hale: *Determination of State Space Matrices for Active Vibration Control Using ANSYS Finite Element Package,* Proc. ASME 45004 vol 1, 24th ASME Conference on Mechanical Vibration and Noise, Chicago, USA, 12-15th August 2012

[3] David E Goldberg: *Genetic Algorithms in Search, Optimization and Machine Learning,* Addison-Wesley Publishing, 1989