PARAMETRIC SYSTEM IDENTIFICATION AND ACTIVE VIBRATION CONTROL OF VIBRATIONAL STRUCTURES USING GENETIC ALGORITHM

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To my beloved mother and father

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ABSTRACT

A vibration system has advantages and disadvantages for us. Some of the disadvantages of the vibration system are discomfort, noise, malfunctioning, wear, fatigue and even destruction. An example of structure that leads to high vibration when subjected to disturbance forces is flexible plate structure. The aim of this research is to develop an Auto Regressive with eXogenous Input (ARX) model characterizing the dynamic behaviour of a two-dimensional (2D) flexible plate structure and the development of active vibration control (AVC) strategies for the structures. In order to construct the model, several sets of vibration data were obtained from the simulation of the flexible plate structures based on finite difference method. The sets of data obtained were utilised to develop ARX model using Least Squares (LS), Recursive Least Squares (RLS) and Genetic Algorithm (GA) methods. The models were validated using one step ahead (OSA) prediction, mean squared error (MSE) and correlation tests. Then, single-input single-output active vibration control (SISO-AVC) was devised using thus developed RLS and GA models. The performance of these systems was assessed in terms of comparison between uncontrolled signals, RLS-AVC and GA-AVC controlled signals in time domain, spectral density and attenuation of the signals in decibel (dB). The results show that GA is the best method in system modeling and vibration control of the simulated 2D flexible plate structures compared to RLS and LS.

ABSTRAK

Sistem getaran mempunyai kebaikan dan keburukan kepada kita. Antara keburukan sistem getaran ialah ketidakselesaan, kebisingan, kerosakan, haus, kelesuan dan kemusnahan. Satu contoh struktur yang mempunyai getaran tinggi apabila dikenakan daya gangguan ialah struktur plat fleksibel. Tujuan kajian ini adalah untuk membangunkan model ARX (*Auto Regressive with Exogenous Input*) yang mewakili getaran dan pembangunan Kawalan Getaran Aktif (AVC) untuk pengurangan getaran plat fleksibel 2-dimensi. Bagi membangunkan model tersebut, beberapa set data getaran diperolehi daripada simulasi yang berdasarkan pada kaedah pembezaan terhingga (*finite difference method*). Data yang diperolehi digunakan untuk membangunkan model ARX dengan menggunakan kaedah *Least Squares* (LS), *Recursive Least Squares* (RLS) dan Algoritma Genetik (GA). Model tersebut dinilai dengan menggunakan ramalan satu langkah kehadapan (OSA), *Mean Squared Error* (MSE) dan *correlation tests*. Kawalan getaran aktif satu-masukan satu-keluaran (*single-input single-output active vibration control*) dibangunkan menggunakan model RLS dan GA yang telah diperolehi. Prestasi sistem-sistem ini dinilai dari segi perbandingan di antara isyarat tiada kawalan dengan isyarat kawalan RLS-AVC dan GA-AVC dalam domain masa, domain frekuensi dan pengurangan isyarat dalam decibel (dB). Keputusan menunjukkan bahawa GA adalah kaedah terbaik bagi pemodelan sistem dan kawalan getaran simulasi plat fleksibel dua-dimensi dibandingkan dengan RLS dan LS.

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A	-	A constant $n \times n$ matrix
$[a_j, b_j]$	-	The domain of variable x_j
a, b, c	-	Coefficients of linear difference equation
$A(q), B(q), C(q), D(q), F(q)$	-	Polynomials of model equation
B	-	Scalar constant related to the time step Δt and mass per unit area, ρ of the plate
C	-	Transfer characteristics of the controller
E	-	Transfer function of the paths through r_e
$e(t)$	-	White noise at time t
$eval(v_k)$	-	Fitness value; k = 1, ... , *population size*
F	-	Transfer function of the paths through r_f
$F(x_i)$	-	Individual fitness
$f(x_i)$	-	Individual's raw performance
$f(\cdot)$	-	A non-linear function
G	-	Transfer function of the paths through r_g
H	-	Transfer function of the paths through r_h
h	-	Thickness of the plate
i	-	Value of variable at each grid points
INC	-	Difference between the fitness of adjacent individuals
L	-	Transfer characteristics of the secondary source
LOW	-	Expected number of trials of the least fit individual
M	-	Transfer characteristics of the detector
m	-	Sections in y direction

MAX	-	Used to determine the bias
MIN	-	Lower bound
m_j	-	Required bits
n	-	Sections in x direction
N_{ind}	-	Population size
$P(t)$	-	Time-dependent variable
p_k	-	Selection probability; k = 1, 2, … , population size
Q_0	-	The equivalent transfer function characterized by $U_C = 0$
Q_1	-	The equivalent transfer function characterized by $U_C \neq 0$
q_k	-	Cumulative probability; k = 1, 2, … , population size
$q(x,y,t)$	-	Transverse external force, with dimensions of force per unit area
r	-	Random number
r_e	-	Distance of detector relative to the primary source
r_f	-	Distance of secondary source relative to the detector
r_g	-	Distance of observation point relative to the primary source
r_h	-	Distance of observation point relative to the secondary source
Sum	-	A real-valued interval
t	-	Time
U_C	-	Secondary signal at the source locations
U_D	-	Primary signal at the source locations
U_M	-	Detected signal
$u(t)$	-	System input at time t
v_k	-	Chromosome; k = 1, ... , *population size*
w	-	Lateral deflection in the z direction

$w_{i,j,k+1}$	-	Deflection of grid points i = 1, 2,…, n and j = 1, 2,…, m at time step $k+1$
$w_{i,j,k}$, $w_{i,j,k-1}$	-	Corresponding deflections at time steps k and $k-1$
x_i	-	Phenotypic value of individual i
x_j	-	Variable
Y	-	Observed signal
Y_D, Y_C	-	Corresponding signal at the observation point
$y(t)$	-	System output at time t
$\hat{y}(t)$	-	Predicted output at time t
β	-	Parameter vector of LS estimation
$\Delta x, \Delta y$	-	Distance between mesh lines in x and y direction
$\varepsilon(t)$	-	Residuals or prediction errors
$\phi_{u\varepsilon}(\tau)$	-	Cross correlation function between $u(t)$ and $\varepsilon(t)$
$\theta = [b_1 \quad b_2 ... b_{nb} \quad f_1 \quad f_2 ... f_{nf}]^T$	-	Parameter vector
ρ	-	The mass density per unit area
ω	-	Frequency in rad/s

LIST OF ABBREVIATIONS

AR	-	Autoregressive
ARMA	-	Auto Regressive Moving Average
ARMAX	-	Auto Regressive Moving Average with eXogenous input
ARX	-	Auto Regressive with eXogenous input
AVC	-	Active Vibration Control
BJ	-	Box-Jenkins
dB	-	decibel
FIR	-	Finite Impulse Response
GA	-	Genetic Algorithm
GA-AVC	-	Genetic Algorithm- Active Vibration Control
LS	-	Least Squares
MA	-	Moving Average
MSE	-	Mean Squared Error
OE	-	Output Error
OSA	-	One Step Ahead
RLS	-	Recursive Least Squares
RLS-AVC	-	Recursive Least Squares- Active Vibration Control
SGA	-	Simple Genetic Algorithm
SISO	-	Single Input Single Output
SISO-AVC	-	Single Input Single Output- Active Vibration Control

CHAPTER 1

INTRODUCTION

1.1 Background

Flexible structures are widely used in engineering system. For example, in civil engineering applications include skyscrapers and bridges, in aerospace structures include propellers, aircraft fuselage and wings, satellite solar panels and helicopter blades and in electromechanical systems include turbo generator shafts, engines, gas turbine rotors and electric transformer cores [1]. Flexible structure systems are known to exhibit an inherent property of vibration when subjected to disturbance forces, leading to component and/or structural damage [2]. That is why the vibration of flexible structure needs to be controlled. The purpose of vibration control in flexible structures is to dampen the response of the structure to external excitation. There are two methods to control vibration; passive and active vibration control (AVC). Active vibration control consists of artificially generating canceling sources to destructively interfere with the unwanted source and thus result in a reduction in the level of vibration at desired locations [2].

Active vibration control is characterized by two complementary processes; identification and control. In the process of identification a suitable model is developed that exhibits the same input/output characteristics as the controlled process (plant). In the process of control a control process is determined, implemented and tested on the plant on the basis of the identified model and control/performance objective [3].

In order to solve an engineering problem (usually of a physical nature), the problem have to formulated as a mathematical expression in terms of variables, functions, equations, and so forth. Such an expression is known as a mathematical model of the given problem. The process of setting up a model, solving it mathematically, and interpreting the result in physical or other terms is called mathematical modeling or briefly, modeling.

1.2 Statement of the Problem

In order to design a controller for vibration system, the mathematical model (mathematical equation) that represent the system must be obtain. Many conventional methods for system identification can be found in the literature, such as Least Squares (LS) and Recursive Least Squares (RLS). However, these methods have the potential risk of getting stuck at local minimum, which often result in poorly identified model [4]. In this project, Genetic Algorithm (GA) identification technique is sought to avoid the problem of convergence to local minima. After the mathematical model is achieved, the project is continued to develop controller using Genetic Algorithm-Active Vibration Control (GA-AVC) and the performance are compared to the conventional RLS-AVC controller.

1.3 Objectives

1) To carry out system identification of vibrational structure using conventional parametric modeling techniques known as Least Squares (LS), Recursive Least Squares (RLS) and intelligent parametric modeling known as Genetic Algorithm (GA).

2) To develop conventional active vibration control using Recursive Least Squares and intelligent active vibration control using Genetic Algorithm.

1.4 Scopes

1) Data acquisition of vibrational structure. The data is obtained from other researcher. The data is simulated based on finite difference method.

2) Parametric modeling using LS, RLS and GA. Modeling is carried out using LS, RLS and GA based on ARX (Auto Regressive with eXogenous input) model and the data obtained.

3) Validation of model using one step ahead (OSA) prediction, mean squared error (MSE) and correlation tests. Validation of model is carried out to observe the performance of LS, RLS and GA.

4) Development of active vibration controller for vibration suppression of the flexible plate structure using conventional RLS-AVC.

5) Development of active vibration controller for vibration suppression of the flexible plate structure using intelligent GA-AVC.

6) Comparative assessment between RLS-AVC and GA-AVC in terms of comparison between uncontrolled signals, RLS-AVC and GA-AVC controlled signals in time domain, spectral density and attenuation of the signals in decibel (dB).