MODELLING AND ACTIVE CONTROL OF FLEXIBLE PLATE USING EVOLUTIONARY METHODS

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A lot of thanks

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ABSTRACT

Flexible structures are very much in demand in the aerospace, marine, civil engineering and robotics industries. Controlling unwanted vibrations on these flexible plate structures is very important to maintain the performance of the structures. To design and develop a good controller, the dynamics of the plate must be modelled adequately. This thesis presents the development of a dynamic characterization of a flexible plate structure using system identification techniques via evolutionary methods and a proportional-integral-derivative (PID) controller for vibration suppression of a flexible plate. Initially, a flexible plate experimental rig was designed and fabricated with a clamped-clamped-free-free (CCFF) boundary condition. Then, data acquisition and instrumentation system were designed and integrated with the rig. Several experimental procedures were conducted to acquire the input and output data of the flexible plate. The input-output data collected from experiments were utilized to develop the model of the system. Several parametric modeling approaches were devised using linear auto regressive with exogenous (ARX) model structure which included the least square (LS), recursive least square (RLS), genetic algorithm (GA) and particle swarm optimization (PSO) techniques. The developed models were validated using one step-ahead (OSA) prediction, mean squared error (MSE) and correlation tests. Amongst all, it was found that the LS algorithm performed better in terms of achieving the lowest MSE as compared to the RLS, GA and PSO performance. Besides, all developed models performed well in estimating the first mode of vibration which is the dominant mode of the structure. It was also found that GA based active vibration control (AVC) using auto tuning method is the best proposed controller for vibration suppression of flexible plate with CCFF edge boundary condition with the highest attenuation value obtained for the first mode of vibration is 112.93 dB.

ABSTRAK

Struktur boleh lentur sangat diperlukan dalam industri angkasa lepas, marin, awam dan robotik. Mengawal getaran yang tidak diperlukan pada struktur boleh lentur adalah sangat penting untuk mengekalkan prestasi struktur. Sistem dinamik untuk plat hendaklah dimodelkan terlebih dahulu sebelum membangunkan sebuah pengawal yang baik. Tesis ini membentangkan pembangunan ciri dinamik bagi struktur plat boleh lentur menggunakan teknik sistem identifikasi menerusi kaedah evolusi dan sebuah pengawal kadar-kamir-pembeza (PID) untuk menghapuskan getaran terhadap plat boleh lentur. Pada mulanya, sebuah rig eksperimen plat boleh lentur direka bentuk dan dibina dengan keadaan sempadan apit-apit-bebas-bebas (CCFF). Kemudian, sistem pemerolehan data dan instumentasi dipasang pada rig. Beberapa kaedah eksperimen dijalankan untuk memperolehi data masukan dan keluaran plat boleh lentur. Data masukan-keluaran yang diperolehi digunakan untuk membangunkan sistem model. Beberapa model parametrik direka menggunakan struktur model linear autoregresif dengan input eksogenus (ARX) termasuklah kaedah kuasa dua terkecil (LS), kuasa dua terkecil jadi semula (RLS), algoritma genetik (GA) dan pengoptimuman kerumunan zarah (PSO). Kesemua model yang dibangunkan disahkan dengan menggunakan kaedah ramalan satu langkah ke hadapan (OSA), min kuasa dua ralat (MSE) dan ujian korelasi. Dari kalangan kesemua model yang dibangunkan, algoritma LS telah menunjukkan keputusan yang terbaik dengan memperolehi nilai MSE yang paling rendah jika dibandingkan dengan algoritma RLS, GA dan PSO. Selain itu, kesemua model yang dibangunkan telah menunjukkan keputusan yang baik untuk anggaran mod getaran yang pertama iaitu mod dominan pada struktur. Didapati juga kawalan getaran aktif (AVC) berasaskan GA dengan menggunakan kaedah penalaan auto merupakan pengawal yang terbaik dalam menghapuskan getaran pada plat boleh lentur dengan keadaan sempadan CCFF dengan nilai pengecilan yang tertinggi pada mod pertama getaran iaitu sebanyak 112.93 dB.

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LIST OF SYMBOLS

S_1	-	Location of accelerometer at detection point
S_2	-	Location of accelerometer at observation point
M_1	-	Mass of flexible plate
$u(k)$	-	Input data
$y(k)$	-	Output data
n	-	Order of model
z^{-1}	-	Back shift operator
$\xi(k)$	-	Zero mean white noise
$a_{1\ldots}a_n$	-	Model parameters
$b_{1\ldots}b_n$	-	Model parameters
$A(z^{-1})$	-	Polynomials with associated parameters
$B(z^{-1})$	-	Polynomials with associated parameters
$\hat{\theta}(i)$	-	Current parameter estimation
$\hat{\theta}(i-1)$	-	Previous estimation vector
$x(i)$	-	Regression vector
$y(i)$	-	System output

λ	-	Forgetting factor
X_i	-	Position of each particle
v_i	-	Velocity vector
P_g	-	Best fitness value
P_g	-	Fittest particle found
rand	-	Random number
c_1 and c_2	-	Acceleration coefficients
w	-	Inertia weight
w_{max}	-	Maximum inertia weight
w_{min}	-	Minimum inertia weight
$iter_{\max}$	-	Maximum number of iterations
$e(t)$	-	Predicted error
$\phi_{ue}(\tau)$	-	Cross correlation function
$\delta(t)$	-	An impulse function
$[\, b_1 .. b_{n_b} \;\; f_1 .. f_{n_f}]^T$	-	Parameter vector
Gen	-	Generation
$f\,(.)$	-	Nonlinear function
$y(t)$	-	System output
t	-	Time domain
$\hat{y}(t)$	-	One step-ahead estimated model output
$y(n)$	-	Actual output of the system
$\hat{y}(n)$	-	Predicted output

a	-	Length of the plate
b	-	Width of the plate
ρ	-	Density
v	-	Poison ratio
t	-	Thickness
E	-	Modulus of elasticity

LIST OF ABBREVIATIONS

AVC	-	Active Vibration Control
P	-	Proportional
PI	-	Proportional Integral
PD	-	Proportional Derivative
PID	-	Proportional Integral Derivative
ARX	-	Auto Regressive with Exogenous
LS	-	Least Square
RLS	-	Recursive Least Square
GA	-	Genetic Algorithm
PSO	-	Particle Swarm Optimization
OSA	-	One Step-Ahead Prediction
MSE	-	Mean Square Error
NI	-	National Instruments
ANFIS	-	Adaptive Neuro-Fuzzy Interference System
ENN	-	Elman Neural Networks
MLPNN	-	Multi-layer Perception Neural Networks
RCGA	-	Real Coded Genetic Algorithm
SISO	-	Single Input Single-Output

SIMO	-	Single Input Multiple-Output
FD	-	Finite Difference
ML-RLS	-	Least Square using Maximum Likelihood Principles
RGELS	-	Recursive Generalized Extended Least Square
BELS	-	Biased Eliminated Least Square Identification
CARARMA	-	Controlled Autoregressive Autoregressive Moving Average
F-RLS	-	Filtering Recursive Least Square
PCM	-	Pulse Code Modulation
LQR	-	Linear Quadratic Regulator
MOGA	-	Multi-Objective Genetic Algorithm
HTGA	-	Hybrid Taguchi-Genetic Algorithm
IPSO	-	Improved Particle Swarm Optimization
FACTS	-	Flexible Ac Transmission System
MPSO	-	Modified Particle Swarm Optimization
USM	-	Ultrasonic Motors
ANC	-	Active Noise Control
FxLMS	-	Filtered-x Least Mean Square
RBF	-	Radial Basis Function
m-PID	-	Modified Proportional Integral Derivative
SF	-	Spread Factor
VSC	-	Variable Structure Control

PZT	-	Piezoelectric
PPF	-	Positive Position Feedback
PWPF	-	Pulse Width Pulse Frequency
CCFF	-	Clamped-Clamped-Free-Free
DDS	-	Direct Digital Synthesis
cDAQ	-	Compact Data Acquisition
ARMAX	-	Auto Regressive Moving Average with Exogenous Input
ARMA	-	Auto Regressive Moving Average
NARX	-	Non Linear Auto Regressive with Exogenous Input
NARMAX	-	Non Linear Auto Regressive Moving Average With Exogenous Input
NARMA	-	Non Linear Auto Regressive Moving Average
MSEE	-	Mean Square Error for Training Data
MSET	-	Mean Square Error for Testing Data

CHAPTER 1

INTRODUCTION

1.0 Background of Study

Recently, the use of flexible structure system for engineering structural applications is rapidly expanding. Basic elements of these flexible structures such as beams, plates, shells and frames are extensively used in the manufacturing industry. Mechanical, civil, aeronautical, marine and aerospace industries reflect the importance and practical significance of the use of these flexible structures. The flexible structure system is known when the flexible structure is subjected to disturbance forces, it will demonstrate an intrinsic property of vibration that will weaken the system and causes structural damages (Tokhi and Hossain, 1994).

The flexible structures are used in diverse engineering applications nowadays, and this has lead for a demand of flexible structures which are reliable, light and efficient. Presently, the flexible plate materials are lighter, thinner and larger. Although, the characteristics of a flexible structure has made it become more functional in the engineering application but, it is also has its downside in the engineering applications. The characteristics of flexible structures which are light, larger and thin actually lead to high vibration. High vibration on these flexible structures will reduce the effectiveness of the flexible structure system. Besides that, if the vibration of the flexible plate is higher, it will cause human discomfort. The potential applications and the problems posed by the flexible plates have received the considerable attention among researchers who are keen to solve the problem of vibration on the flexible structure system with complex boundary condition (Ismail, 2006).

Normally, a researcher will alter the geometry or boundary condition of the flexible plate to prevent failure in the flexible plate. Altering the geometry of flexible plate is a general mechanical method where it is dependent on knowledge about the frequency of vibration sources. The problem of this method is that anticipation of the frequency of disturbance is based on the time dependent characteristics of the destructive vibration which, at times may be impossible to be achieved. Passive and active control methods are two control strategies used to reduce the amplitude of the destructive vibration in a flexible plate structure. The passive control method consists of mounting passive material. For example, dynamic absorbers and vibration dampers use mass spring damper decoupling on a structure. On the other hand, the active control method known as active vibration control (AVC) basically introduces a secondary source of vibration to the dynamical system for reducing the amplitude of vibration (Tavakolpour, 2010).

The key of effectiveness for control the vibration of the flexible plate by obtain an accurate or approximate dynamic model of the flexible plate structure. Developing an accurate dynamic model of a plate structure will help to give the best result in control the vibration and the way to design the good controller for vibration suppression of the flexible plate (Tavakolpour, 2010). Analysis of the vibration on the plate has been studied extensively in the few last few decades especially focusing on the various shapes and configurations of a flexible plate structure. Initially, the analysis has been about the simple cases, such as limited boundary condition and the geometries. This could be due to the lack of computational facilities at that time and it must have been difficult to obtain accurate results from the analysis. Nowadays, the situation is already changed because of the advancement and upgrades in the computational system and also various efficient numerical methods. There are more researchers in this area and the results of their research are also more accurate (Al-Khafaji, 2010).

Active vibration control (AVC) has been getting attention of researchers in this field recently. The main purpose of AVC is to reduce the amplitude of a dynamical system by generating a secondary source to the dynamical system. AVC uses the superposition waves by introducing a secondary vibration to destruct an unwanted vibration source which will reduce the vibration level to the desired location (Mat Darus and Tokhi, 2005). Alternatively, AVC can be explained when a disturbing vibratory signal that is sensed by an appropriate transducer with suitable transfer function which will be processed by the designed controller. Then, the control signal will be fed to the actuator to build a secondary force signal. In fact, the AVC is more efficient as compared to the passive control method. Other than that, AVC is able to control any unnecessary vibration in the broad band frequency and this is one of the reasons that this type of control is getting more attention from researchers and engineers nowadays (Tavakolpour, 2010).

1.1 Statement of Problem

Disturbance vibration on a flexible plate will affect the performance of the flexible structure. Thus, removing unwanted vibration on the flexible plate structure is necessary. Active vibration control (AVC) is a method that can solve low vibration control problems and it has many advantages compared with the traditional vibration control. Mat Darus, *et al.*, (2007) has reported the development of the active vibration control (AVC) for flexible plate structure that uses the genetic algorithm (GA) strategy. The development of the GA is used to obtain a dynamic model of a flexible plate structure. Another research by Julai, *et al.*, (2010) presented the development of active vibration control of a flexible structure by using the particle swarm optimization (PSO). The optimization technique was utilized to obtain a dynamic model of a flexible plate structure that uses auto regressive with exogenous (ARX) input structure. In another study, Ismail, (2006) presented a system identification of flexible structure that uses Neural Network. This research investigated the development of a system identification approach for the modeling of a two dimensional of flexible plate structure.

Many of the research relied on simulation data to obtain the characterization of a flexible plate. However, in this research, vibration data set of flexible plate was collected by conducting experiments in laboratory and a flexible plate was clamped at the 2 side edges, while the top and bottom of the flexible plate was free clamped is used in experimental rig. Thus, the two main purposes of this research are to characterize the clamped-clamped-free-free (CCFF) flexible plate structure using system identification techniques and to develop a PID controller using evolutionary methods for vibration control of the flexible plate.

The input output data of the flexible plate structure for the whole previous research mentioned above was acquired from simulation using finite difference method. Therefore, in this research the data input output of a flexible plate structure will be obtained from the experimental data. The performance of the system identification developed in this research using Least Square (LS), Recursive least square (RLS), Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) were validated and compared with each other. Then, a PID controller was developed for vibration suppression of flexile plate based on active vibration control technique.

1.2 Objectives

There are two main objectives of this research:

i. To model the clamped-clamped-free-free (CCFF) flexible plate structure using system identification techniques approaches by conventional and intelligent parametric modeling.
ii. To develop a PID controller for suppression of unwanted vibration of the CCFF flexible plate structure.

1.3 Scope of Study

i. Use of experimental test rig and National Instrumentation Data Acquisition System to acquire the vibration data of the flexible plate.

ii. Use of parametric modeling for the CCFF flexible plate structure based on conventional parametric modeling approach such as Least Square (LS) and Recursive Least Square (RLS), and intelligent parametric modeling approach such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO).

iii. Validate the developed models using a one step-ahead prediction (OSA), mean squared error (MSE) and correlation tests.

iv. Develop a PID controller using Matlab SIMULINK for vibration suppression of the CCFF flexible plate structure.

1.4 Research Methodology

The flowchart in Figure 1.1 describes briefly the research methodology considered in this study.

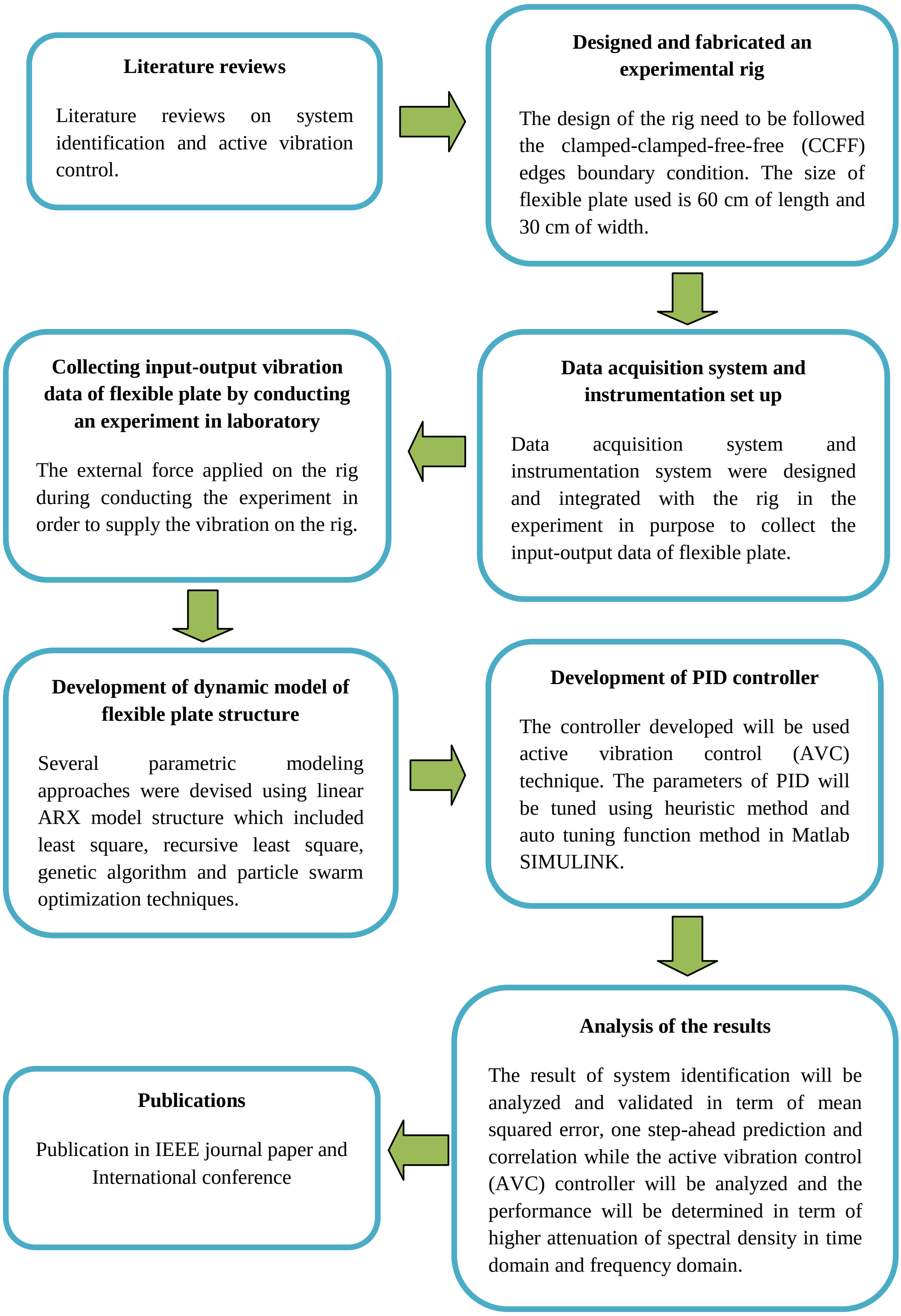

Figure 1.1 : Flowchart of study

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