PARAMETRIC IDENTIFICATION OF FLEXIBLE BEAM SYSTEM USING EVOLUTIONARY ALGORITHM

by

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LIST OF ABBREVIATIONS

ABC	Artificial bee colony
AIS	Artificial immune system
ARX	Auto regressive with exogenous inputs
BA	Bat algorithm
BBOA	Biogeography based optimization algorithm
BFA	Bacterial foraging algorithm
CS	Cuckoo search
DAQ	Data acquisition system
DE	Differential evolution
EAs	Evolutionary algorithm
FA	Firefly algorithm
FEM	Finite element method
GA	Genetic algorithm
GSA	Gravitational search algorithm
LS	Least square
MSE	Mean square error
NI	National instrument
OSA	One step ahead prediction
PD	Proportional derivative
PID	Proportional integral derivative
PSO	Particle swarm optimization
PZT	Piezoelectric lead zirconate titanate
RLS	Recursive least squares
SA	Simulated annealing
SI	Swarm intelligence

LIST OF SYMBOLS

α	Randomization parameter
β	Attractiveness
γ	Light absorption coefficient
A	Loudness of sound
f	Frequency of sound
r	Pulse rate of sound
u(t)	Input signal of system
y(t)	Measured output signal of system
ŷ(t)	Predicted output
t	Discrete time index
ε(t)	Model prediction error
n_a,n_b	Polynomials order
a, b	Unknown parameters to be estimate
f(x)	Old solution
f(x*)	New solution
rand	Random number
Ii	Less bright firefly
Ij	Brighter firefly
Φ(N)	Input-output vector
Y(N)	Output vector
$Y(N)^T$	Transpose of output vector
φ	Vector of input-output signals
J	Fitness function
E(N)	Difference between model output and measured output

$\hat{\theta}$	Estimated parameters to be determined
ω_i	i-th natural frequency
ξ_i	Damping ratio
z^{-1}	Backshift operator

Pengenalan Parametrik Sistem Rasuk Fleksibel Menggunakan Algoritma Evolusi

ABSTRAK

Aplikasi struktur fleksibel dalam bidang kejuruteraan tersebar luas kerana ringan dan kepentingan teknikal. Sebelum membentuk sesuatu sistem, ciri-ciri dinamik sistem perlu dikaji dengan membangunkan model matematik. Pendekatan berasaskan model seperti kaedah elemen terhingga yang biasa digunakan dalam pemodelan biasanya memerlukan pengetahuan yang luas tentang sistem yang akan dikaji dan melibatkan persamaan kompleks. Dalam teknik pengenalan sistem, anggaran parameter konvensional lazimnya digunakan dan tetapi kekurangannya, ia boleh menyebabkan penyelesaian terperangkap dalam optima tempatan dan mengurangkan kecekapan model. Oleh itu, dalam kajian ini, model rasuk fleksibel dibangun dengan menggunakan kaedah pengenalan sistem yang berdasarkan data eksperimen yang dikumpulkan dari rig eksperimen dan menggunakan algoritma evolusi (EA) sebagai teknik penganggaran. Penyelidikan ini menyediakan platform baru untuk penyelidik lain untuk membangunkan model berdasarkan teknik pengenalan sistem menggunakan EA untuk sistem atau aplikasi lain. Selain itu, ia juga memberikan asas untuk kajian masa depan mengenai analisis prestasi EA dari segi tetapan parameter yang berbeza berbanding dengan algoritma lain. Satu percubaan untuk mendapatkan model linear dicapai dengan membangunkan rasuk eksperimen rasuk fleksibel menggunakan isyarat gelombang persegi dengan mencampurkan kekerapan resonans untuk mengumpul data input dan output. Auto-regresif dengan input eksogen (ARX) dipilih sebagai struktur model sistem. Parameter pekali struktur model dianggarkan melalui EA seperti algoritma kelip-kelip dan algoritma kelawar. Beberapa set tetapan parameter untuk FA dan BA diuji untuk memeriksa kesan tetapan kepada prestasi model. Model terbaik yang diperolehi dari setiap kaedah anggaran dibandingkan dengan algoritma ‘least square’ dan disahkan menggunakan kaedah min kesilapan persegi (MSE) dan satu ramalan ke hadapan (OSA). Keputusan utama menunjukkan bahawa FA-estimasi mempunyai MSE 9.46E-5 yang paling rendah di antara semua kaedah anggaran dan anggaran BA juga mengatasi prestasi LS (1.16E-2) dengan memperoleh MSE yang lebih rendah iaitu 2.70E-4. Keseluruhan kajian ini membuktikan bahawa algoritma evolusi dapat menghasilkan prestasi yang lebih baik daripada algoritma konvensional. Algoritma kelip-kelip dan algoritma kelawar adalah berkesan dan mampu digunakan dalam bidang pengajian seperti aplikasi kejuruteraan lain.

Parametric Identification of Flexible Beam System Using Evolutionary Algorithm

ABSTRACT

An application of flexible structures in engineering is spread extensively due to lightweight property and technical importance. Before implementing the system, the dynamic behavior of the system needs to be studied by developing a mathematical model. The model-based approach like finite element method which commonly used in modeling usually required a wide knowledge on the system to be studied and involves complex equations. In system identification technique, the conventional parameter estimation is commonly applied and the limitation is, it may cause the solution trapped in local optima and reduce the efficiency of the model. Therefore, in this study, the model of flexible beam is developed by using system identification method which is based on experimental data collected from the experimental rig and using evolutionary algorithm (EAs) as estimation technique. This research provides a new platform for other researcher to develop a model based on system identification technique using EA's for other system or application. Other than that, it also delivers a basis for future study on analysis of the performance EAs in terms of different parameter settings in comparison with other algorithms. An attempt of obtaining the linear model is accomplished by developing an experimental rig of flexible beam using square wave signal with mixing resonance frequency to collect input-output data. Auto-regressive with exogenous inputs (ARX) is chosen as a model structure of the system. The coefficient parameters of model structure are estimated via EAs such as firefly algorithm and bat algorithm. A few sets of parameter settings for FA and BA are tested to examine the effect of settings to the performance of model. The best models obtained from each estimation method are compared with least squares algorithm and validated using mean square error (MSE) and one step-ahead prediction (OSA). The main result shows that FA-estimation has MSE of 9.46E-5 which is the lowest among all the estimation method and BA-estimation also outperformed LS-estimation (1.16E-2) by getting lower MSE which is 2.70E-4. Overall of this study proved that evolutionary algorithm able to produce better performance than conventional algorithm. Firefly algorithm and bat algorithm is effective and capable to be used in this area of study like other engineering application.

CHAPTER 1

INTRODUCTION

1.1 Background of study

Since the past decades, the utilization of the flexible structures is spread broadly especially in engineering area due to lightweight property. The elements of the flexible structure such as frames, shells, beams and plates are usually found to be used in fabrication of aircraft, solar panel, bridge decks and flexible manipulators of satellite and robotics systems (Al-Khafaji, 2010). The dynamic behaviour of flexible structure has received a great attention due to its technical importance. The beam element in flexible structure tends to has a thickness much smaller than its dimensions which yielding a 'thin-walled' type structure. If the beam is subjected to external forces, it may exposed to vibration due to the stability of the structure (Chakraverty, 2009).

In this study, the flexible beam is considered as a system to be studied. One of the examples of flexible beam's application is a wing of an aircraft. In the midst of the operation, the external disturbances like winds exerted on the system may lead to vibration and this is certainly because of low damping characteristic of the flexible structure. The extreme vibration contributes to the production of noise, wears of mechanical components, human discomfort and also reduced system effectiveness.

In order to control the vibration effectively, it is required to obtain a good model of the structure, which will result in good control (Darus & Al-Khafaji, 2012). A dynamic system of a structure can be modeled via system identification method.

System identification is a technique of developing a mathematical model of a dynamic system based on the observed data. The model acts as a benchmark of designing the controller. This method becomes a considerable interest among the research community over many years in various fields of science and technology (Gotmare, Bhattacharjee, Patidar, & George, 2016). For instance, a few researchers such as Tavakolpour, Nasib, Sepasyan, & Hashemi, (2015) employed parametric and non-parametric system identification for modeling of a turbojet engine. Theisen, Niemann, Santos, Galeazzi, & Blanke, (2016) implemented system identification for modeling and control of gas bearing. Besides that Yu, Feng, & Hahn, (2016) also modeled the rotor bearing foundation system by using system identification for balancing and efficient running of turbo machinery.

Basically, there are four main phases in system identification; extraction of input and output data from the system, selection of model structure, parameter estimation, and validation of the model. Theoretically, EAs is an optimization or searching technique which based on the principle of natural evolution. The searching performance of the EAs is better than conventional approach. This is due to random and global exploration which is adopted in EAs working principle (Darus & Tokhi, 2006). The searching range of solutions is wider and solutions found may have a high probability of being optimum.

In this study, the model of the flexible beam system is developed using system identification by comparing parameter estimation approach between evolutionary algorithm (firefly algorithm and bat algorithm) and conventional method (least squares algorithm). Firefly algorithms (FA) and bat algorithm (BA) are proposed to explore the potential of the algorithms in flexible beam application. Firefly algorithm searching the solutions based on the flashing light behavior for attracting partners and bat algorithm is based on echolocation which used to detect prey in the dark.

Both algorithms mimic the same process in real life to search the solutions. Literally, application of FA and BA are wide and found in few fields. For examples, Mohanty, (2016) applied FA for design optimization of a shell and tube heat exchanger, Rahmani, Ghanbari, & Ettefagh, (2016) proposed adaptive fractional order proportional integral derivative (PID) sliding mode controller using BA to control caterpillar robot manipulator and Konstantinov and Baryshnikov, (2017) performed a comparative analysis of several EAs for optimization of proportional derivative (PD) controllers.

The experimental data is collected using square wave signal with mixing resonance frequency as input signal to excite the beam. The model structure selected is auto-regressive with exogenous inputs (ARX). The coefficient parameters of model structure are estimated by the estimation algorithms. The value of parameter setting for each algorithm is set within the limits stated in theory. The performance of the model is validated via mean square error (MSE) to find the model with minimum error and the best parameter settings value of each algorithm are selected.

Besides that, one step-ahead (OSA) prediction result is plotted to compare the predicted output and the measured output. Finally, all the models from different estimation methods are compared and the best model with minimum MSE is selected.

1.2 Problem statement

The vibration control of flexible beam is often influenced by the accuracy of the system's model. However, it is very crucial to obtain an accurate model of the structure possibly with minimum error. The model-based approach like finite element method (FEM) always used in modeling a system. It is commonly revealed in previous works (Zoric, Simonivic, Mitrovic, & Stupar, 2013; Parameswaran & Gangadharan, 2014; Mirafzal, Khorasani, & Ghasemi, 2015). However, FEM is limited to the simulation of an actual system based on its properties such as the dimension of a system, young modulus, and density.

The process of determining the mathematical model using FEM is quite complex, which involved the dynamic equations of motion and also required a wide knowledge of the principle of beam theory (Sethi & Song, 2005). Modeling using FEM is not focused on the equations of beam structure only, but also related to the motions of each item attached to the surface of flexible beam such as piezoelectric patch (Kumar, R.Srivastava, & R.K.Srivastava, 2014). Therefore the well-developed method like system identification can be used to model the flexible beam system, which required zero knowledge about the system and the model can be formulated using real experimental data. Furthermore, this model can be used for controller design.

Parameter estimation is one of the phases in system identification technique. Based on previous research, conventional estimation algorithm such as least squares (LS) is often implemented. However, the solutions found by using this algorithm is trapped in local optima, which may cause the solutions are limited in the certain area only. It also does not evaluate many points (solutions) in searching space (Tavakolpour, Darus, Tokhi, & Mailah, 2010). All the solutions found in that area maybe not optimal or suboptimal and the solutions do not converge towards global optima. If the method of parameter estimation is enhanced with an intelligent method like evolutionary algorithms (EAs), the performance of the model could be improved. This is because EAs mimics the natural evolutionary process for problem-solving and it works based on the principle of a global search to obtain an optimal solution (Darus & Tokhi, 2006).

1.3 Objectives of study

The objectives of this study consist of:

1. To develop an experimental rig of flexible beam system for experimental data collection.

2. To develop a mathematical model of flexible beam system using parameter estimation technique by means of firefly algorithm and bat algorithm.

3. To analyse the performance of firefly algorithm and bat algorithm in searching of solutions, validate the models through validation tests and compare performance of the model with the conventional approach.

1.4 Scope of study

The scopes of the study are highlighted as follow:

1. Develop experimental rig for flexible beam system using the aluminum beam.

2. Analyse the dominant modes of the flexible beam via resonance test.

3. Input and output data collection by applying square wave signal with mixing resonance frequency as an excitation signal to the flexible beam.

4. Modeling the flexible beam using system identification technique and estimate the parameters of the autoregressive with exogenous input (ARX) model structure using least square, firefly algorithm, and bat algorithm in MATLAB software.

5. Study the performance of firefly algorithm and bat algorithm with several sets of parameter settings as shown in Table 1.1.

Table 1.1: Parameters settings used in estimation

Firefly algorithm			Bat algorithm		
Set 1	Attractiveness, β	1.0	**Set 1**	Loudness, *A*	1.0
	Light absorption coefficient, γ	0.1		Frequency, *f*	1.0
	Randomization parameter, α	0.1,0.3,0.5		Pulse rate, *r*	0.1,0.3,0.5
Set 2	Attractiveness, β	1.0	**Set 2**	Loudness, *A*	1.0
	Light absorption coefficient, γ	1.0		Frequency, *f*	5.0
	Randomization parameter, α	0.1,0.3,0.5		Pulse rate, *r*	0.1,0.3,0.5
Set 3	Attractiveness, β	1.0	**Set 3**	Loudness, *A*	1.0
	Light absorption coefficient, γ	10.0		Frequency, *f*	10.0
	Randomization parameter, α	0.1,0.3,0.5		Pulse rate, *r*	0.1,0.3,0.5

6. Study the performance of estimated models and validate the models via mean square error (MSE) and one step-ahead (OSA) prediction.

1.5 Significance of study

To date, application of firefly algorithm and bat algorithm in parameter estimation is limited. An attempt has been made to propose these algorithms has provide a new platform for other researcher to develop a model based on system identification technique using FA and BA for other system or application. Besides that, this study provides a basis for future study on analysis of the performance of FA and BA in terms of different parameter settings in comparison with other algorithms.