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RESEARCH ARTICLE

Implementation of Evolutionary Algorithms to Parametric Identification of Gradient Flexible Plate Structure

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ABSTRACT - This paper focused on modelling of a gradient flexible plate system utilizing an evolutionary algorithm, namely particle swarm optimization (PSO) and cuckoo search (CS) algorithm. A square aluminium plate experimental rig with a gradient of 30° and all edges clamped were designed and fabricated to acquire input-output vibration data experimentally. This input-output data was then applied in a system identification method, which used an evolutionary algorithm with a linear autoregressive with exogenous (ARX) model structure to generate a dynamic model of the system. The obtained results were then compared with the conventional method that is recursive least square (RLS). The developed models were evaluated based on the lowest mean square error (MSE), within the 95% confidence level of both auto and cross-correlation tests as well as high stability in the pole-zero diagram. Investigation of results indicates that both evolutionary algorithms provide lower MSE than RLS. It is demonstrated that intelligence algorithms, PSO and CS outperformed the conventional algorithm by 85% and 89%, respectively. However, in terms of the overall assessment, model order 4 by the CS algorithm was selected to be the ideal model in representing the dynamic modelling of the system since it had the lowest MSE value, which fell inside the 95% confidence threshold, indicating unbiasedness and stability.

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1.0 INTRODUCTION

The superiority of flexible plate structures such as lightweight, lower maintenance, lower energy consumption, and faster response intrigues various engineering industries like solar panels, bridge decks, aircraft [1], and ship bodies [2] as well as conveyor systems [3]. Despite the numerous benefits that a flexible structure provides, it is easily affected by vibration due to the presence of disturbance forces. Thus, the unwanted vibration leads to plate structural fatigue and durability problems which affect the plate stability and performance. Subsequently compromising the safety of working environments [4].

Unwanted vibration must be reduced for the plate's performance to be maintained. Therefore, passive vibration control (PVC) has been proposed. PVC primarily involves modifying the dynamic characteristics of the structure by adding an absorber and damper to prevent excessive vibration on the plate. The increase in weight structure, however, limits PVC, as this technology cannot sustain low-frequency vibration on the flexible plate. Therefore, active vibration control (AVC) is consequently introduced. The AVC is a method of suppressing undesired vibration by interfering with the principal disturbance source. To create a successful AVC scheme, the system modeling must be realistic enough to replicate the actual dynamic characteristics of the structure [5].

Dynamic model identification by experimentation is an effective way to obtain dynamic modelling. The characteristics of a complex structure normally identified in the nonlinear system can be included in the dynamic model. Researchers have used the System Identification (SI) method to model systems that approximate physical system behavior under diverse operating situations. Based on the observed input-output data, this method is used to determine the accurate model of a dynamic system [6]. A decent model can be found by employing an appropriate estimation optimization approach. Nowadays, many researchers employ evolutionary algorithms (EA) in their optimization efforts to identify the optimum model because EA has been proven to be effective.

For instance, particle swarm optimization (PSO), which was inspired by the intelligent social behaviour of social organisms such as flocks of birds and schools of fish, has gained researchers' attention in various optimization problem-solving due to its fast convergence as well as fewer parameters that need tuning [7]. For a similar system in research, Khoooshechin et al. investigated the optimal parameters of flexible square cascade multicomponent isotopes. The outcome showed PSO optimization managed to increase the enrichment of each isotope at any concentration [8]. Besides, Negri et al. obtained the natural frequencies and mode shapes by using the simulational model updating method that utilized PSO optimization [9]. In [10], the researchers used an improved PSO algorithm with a two-stage optimization approach to efficiently accelerate particle swarm optimization (EAPSO) for estimating the localization and quantification of the damaged elements in plate structures. Meanwhile, Wang et al. utilized PSO optimization to calculate the optimum

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combination of parameters of arc length for the curve interpolation method for interpolating the stress field of a wind tunnel flexible plate [11]. Besides, Julai et al. [12] optimized the control parameters using PSO for a flexible plate for vibration cancelation.

Another widely used EA in engineering applications is the Cuckoo search (CS) algorithm, which was inspired by the reproduction strategy of cuckoo birds. The ability to converge optimally in global search problems makes it extensively used by researchers for optimization issues [13]. For example, Chavan and Pawar employed the CS algorithm for optimization, maximization of density and minimization of cycle time on the cold chamber die-casting process [14]. In [15], Tran-Ngoc et al. utilized the CS algorithm by improving the weight and bias parameters of Artificial Neural Network (ANN) to minimize the differences between real and desired outputs on steel bridge beam-like structures [16]. Another study that uses CS as an optimization approach is in [17], where the optimum parameters for both the parametric estimation in modelling development and the PID controller's parameters for a single-link flexible manipulator are determined. Besides, [18] studied the optimization of the proportional-derivative (PD) based controller parameters by CS algorithm for the control scheme of a single-link flexible manipulator. Apart from that, Xu et al. investigated the vibration structural damage identification by using CS algorithm on detecting the local damages from the nonlinear objective function established by utilizing the natural frequencies and modal assurance criteria [19].

It can be concluded that PSO has fast convergence and use few parameters. Meanwhile, CS is very effective in solving global optimization, and it has single parameters to be adjusted. The advantages of PSO and CS highlighted hereby have prompted an investigation into their capabilities. Therefore, this study aims to use both PSO and CS algorithm with a system identification approach to model a flexible plate structure tilted at a gradient of 30°. The attained model is validated in terms of input/output mapping, Mean square error (MSE), correlation test, and pole-zero stability diagram. The outcome of the study would determine the suitability of the EA algorithm for a gradient flexible plate. This will serve as a starting point for further improvements to the algorithm.

2.0 EXPERIMENTAL SETUP

An experimental setup was conducted to acquire the input-output vibration data from a 30° gradient flexible plate structure. Firstly, the experimental rig of 30° gradient flexible plate structure was designed then fabricated. The input-output vibration data were acquired experimentally by integrating National Instruments (NI) data acquisition and instrumentation system. A square aluminium thin plate was used in the experiment with a dimension of 50 cm × 50 cm × 0.15 cm with a gradient of 30°. The edges of the experimental rig were fully clamped. The specification of the 30° gradient flexible plate used in this study were listed in Table 1.

Table 1. The specification of the experimental rig

Specification	Value
Dimension (length×width×thickness) and orientation	0.5×0.5×0.0015 m with 30° gradient
Number of sections	10×10
Density, ρ	2.71×10^3 kg/m^3
Mass moment of inertia, I	5.19×10^{-11} kg.m^2
Modulus of elasticity, E	7.11×10^{10} N/m^3
Poisson's ratio, v	0.3

A magnetic shaker (S 50018) was placed on the excitation point of the experimental rig to generate the actuation force. The magnetic shaker was connected to a function generator (GFG-82155A) through a power amplifier (BAA 60) to create a sinusoidal actuation force. Two pieces of piezo-beam type accelerometer (PCB Piezotronics-353B33 and Kistler-8640A50) were attached at the observation and detection point, respectively to acquire the acceleration signal that represents the vibration of the 30° gradient plate structure. The sampling times were set to 0.003 s. The piezo-beam type accelerometers were connected to the NI data acquisition system (NI 9232 and NI 9263) mounted on the NI Compact-DAQ (portable NI cDAQ-9174) is connected to the personal computer. A personal computer equipped with a 10th Generation Intel® Core™ i3-10105 Processor, 16GB RAM, and MATLAB R2018A software were used to analyze the required signal obtained from the experiment. The experimental setup and integration system are shown in Figure 1 to Figure 3, respectively.

3.0 SYSTEM IDENTIFICATION

SI method was defined by developing the model of the system based on the input-output of experimental data [4]. SI steps consist of data acquisition, model structure selection, parameter estimation, and model evaluation. In this study, the model was developed using an autoregressive with exogenous input (ARX) and the model parameters were estimated using a conventional algorithm which is the RLS and PSO as well as CS algorithm.