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FE model updating using artificial boundary conditions with genetic algorithms

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Abstract

In the realm of finite element (FE) model updating and damage identification, an outstanding issue is with the limited amount of reliable response data that may be used to perform an inverse procedure. This problem can restrict the number or types of physical parameters that may be identified or updated, and it could also result in an erroneous identification of the parameters due to insufficient sensitivity of the data set. To tackle this problem, an effective enlargement of the data set is desired. This paper presents a genetic algorithm (GA)-based methodology to make effective use of the artificial boundary condition (ABC) frequencies for FE model updating. The ABC frequencies can be obtained through the measurement of the incomplete frequency response functions of the structural system with a limited number of sensors, and thus they can be of similar measurement accuracy as the natural frequencies. In the present methodology, a binary coding GA is proposed for the selection of the desired artificial boundary conditions; while for the actual updating of the FE model, a procedure based on a real coding GA is implemented. Numerical examples are provided to demonstrate the effectiveness of the proposed approach in the FE model updating.

Keywords: Finite element model updating; Modal frequencies; Artificial boundary; Omitted coordinate set system; Sensitivity analysis; Genetic algorithm (GA)

1. Introduction

In the establishment of a representative FE model for an actual structure, a large number (order of $10^2 \sim 10^3$) of physical parameters may be required in order to define the model accurately. The determination of these parameters constitutes a typical model updating process in which the FE parameters are adjusted until the predicted data of the structure by the FE model, such as the natural frequencies and mode shapes, match the available measured counterparts. However, from the measurement point of view a typical modal test on a structure may enable the determination of only a much smaller number (order of 10^1) of modal parameters that may be useful in guiding the adjustment of the FE model parameters [1]. This gives rise to an underdetermined problem. Although through rational reduction of the number of model variables the demand on the amount of measured data may be alleviated, an enlargement of the measured modal dataset is always desired.

For dynamic FE model updating, the resonant frequency data are usually included because these frequencies are closely related to the overall structural parameters and they can be measured with generally good accuracy. In fact, some early studies on the damage identification used solely the natural frequencies [2,3]. However, the number of measurable natural frequencies is usually limited, whereas for local changes to be identified the use of very high order frequencies is required. Moreover, the use of frequency data alone will face difficulty for a structural system

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of a symmetric setting. The consideration of mode-shape data is a possible way to tackle these problems; however, the generally large measurement errors in mode shapes seriously limit the applicability of such data in many cases.

To expand the frequency dataset, some researchers have tried to obtain additional sets of resonant frequencies of the same structure with however different boundary conditions that are imposed physically on the structure. For example, Li et al. [4] described a procedure called ‘‘perturbed boundary condition (PBC)’’ testing, in which different boundary conditions and additional masses may be applied at some selected points of the structure. Since this method requires physical modifications to the structure during the testing and a separate test is needed for each different configuration, it is difficult to implement in practice.

Recently, a method called ‘‘artificial boundary method (ABM)’’ [1,5] has been developed. Concerning FE model updating and damage identification, ABM can be a promising and practical approach. With ABM, it is possible to obtain with good accuracy a large number of additional and distinctive mode frequencies from the same modal test conducted for extracting the natural frequencies, without any physical modification to the structure. The only information required is the incomplete frequency response function (FRF) matrix corresponding to those DOFs where the desired boundaries are ‘‘artificially’’ applied. These additional mode frequencies correspond exactly to the natural frequencies of the structure when those DOFs are restrained to the ground. In this way, many sets of natural frequencies can be obtained from a conventional modal test, and each set corresponds to the same state of the structure but under different boundary conditions with extra artificial pin-supports. Theoretically speaking, there is no limit to the number and the location of extra pins to be applied on a continuous structure; but for practical reasons an effective choice of extra pins has to be made prior to the actual test.

So far the application of ABM in FE model updating has been quite limited. Some exploratory studies are found to use anti-resonant frequencies [6,7], which is a special case of ABM method with one artificial pin. In these works, the updating is performed using the traditional eigensensitivity method, which is subject to several restrictions (see [9]). The location of the extra pin used in the generation of anti-resonant frequency data was determined in a rather arbitrary manner, for example, in reference [7], it was taken as effective to use anti-resonant frequencies associated with two pins located somewhere at the top of a flexible truss tower for updating the model. A trial-and-error approach was also used [17], with consideration of the condition number of a generalized sensitivity matrix as the selection criterion. Generally speaking, there lacks a systematic and generally applicable approach to identify a proper configuration of the artificial pin(s) for an effective implementation of ABM in a particular FE model updating.

In this paper, the artificial boundary method is applied to generate extra modal frequency data (called ‘‘ABC frequencies’’) for FE model updating. To determine a suitable configuration for the ABCs, a method using binary genetic algorithm (GA) is proposed. The search domain of GA consists of all the measurable DOFs of a structure. Each chromosome represents an artificial boundary configuration. The fitness of a chromosome is evaluated according to the effectiveness of the corresponding ABC frequencies assessed via a sensitivity analysis. Considering the possible large variation range of the variables and also the high nonlinearity nature (and hence many local optima) of the inverse model updating problem, a robust real coding GA capable of performing global optimization is used in the actual updating procedure involving both natural and ABC frequency data. The implementation of both the proposed binary GA-based ABC selection procedure and the updating process using real coding GA is demonstrated with numerical examples of portal frames.

2. Overview of genetic algorithms (GAs)

GAs are very powerful global optimization methods derived from the ideas in the science of genetics and the process of natural selection of biology. GAs implement a stochastic searching procedure and operate with a population of chromosomes, which are genotype representation of the physical variables. The feasible space of variables is continuously explored by GAs in search of the optimal variable set by using two genetic operators, namely, *crossover* and *mutation*. Through the application of *selection*, *crossover* and *mutation* on the current population, a likely better new population will be generated. In general, this process repeats for a number of times (generations) before satisfactory results are reached [8].

GAs are considered to be a desired solution tool for the problems dealt with in the present study. The reasons are two folds: (a) The optimal choice of artificial pins is essentially combinatorial problem for which the derivative information is not available and therefore, the conventional optimization methods such as the conjugate gradient scheme cannot be applied; GAs, however, require only the construction of an objective function that may be evaluated, and this can be achieved one way or the other for a particular problem. (b) For the actual FE model updating procedure, GAs are also considered to be a viable search engine because of their global search capability. A general objective function often contains many local optima, and the traditional optimization methods would experience difficulties or even failure due to the existence of such local optima.

In general, GAs start with an initial population which is usually obtained through random sampling. The choice of the population size depends on the problem under consideration. This population consists of a number of strings, or chromosomes in genetics terms. Each chromosome is actually formed by a concatenation of the geno-space representation (or coding) of each physical variable. Depending on the nature of the problem, the coding can be in different