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An improved procedure for updating finite element model based on an interactive multiobjective programming

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ABSTRACT

Finite element model updating is an optimization problem to identify and correct uncertain modeling parameters. In conventional model updating, physically incompatible criteria, which designate differences between analytical and experimental results, are combined into a single-objective function using weighting factors. There are no general rules for selecting the weighting factors since they are not directly related to the dynamic behavior of the updated model. Thus, a necessary approach is to solve the time-consuming optimization problem repeatedly by varying the values of weighting factors until a satisfactory solution is obtained. In this work, an interactive multiobjective optimization technique called satisficing trade-off method is introduced to avoid the difficulty. It is relatively easy to state what kind of solutions is satisfactory considering the correlations of the initial FE model with the experimental results, the importance of individual modal properties, and measurement errors, etc. The satisficing trade-off method uses this information directly in the optimization process and finds a Pareto solution which is nearest to the given information. Moreover, as the method provides the tangent hyperplane which approximates the Pareto surface in the neighborhood of the obtained Pareto solution, the desired updated model can be found in a few iterations.

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1. Introduction

Finite element (**FE**) models are very useful for design, development, and application phase of mechanical structures. FE models allow to predict the dynamic behavior of structures under various loading and boundary conditions. They also can be used to study the effects of structural changes. However, results obtained from FE models often differ from test results. So, they need to be verified and, if necessary, updated for further applications. FE model updating is a procedure to minimize differences between analytical and experimental results that leads to better predictions of the dynamic behavior of the structure. Thus, FE model updating is a kind of optimization problems.

Although all real structures have infinite numbers of degrees of freedom (**DOFs**) and modes, the data that can be obtained from modal tests are quite limited for practical reasons. On the other hand, FE models consist of many finite elements, extending in many cases to several thousands. Thus, due to the inherent limitations of experimental data, the number of parameters which can be used to modify an FE model far exceeds that of the measured data of a target structure. There can be numerous modified or updated FE models that agree with the incomplete test data [1]. But, if the aim of model

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updating is not simply to mimic the incomplete test results, there must be some restrictions on the selection of updating parameters and their allowable changes so that the updated model retains its physical foundations. In that case, while there is truly no precise solution, there are actually many approximate solutions [2]. Thus, the updated model is just one of approximate solutions which is determined according to the specified criteria or objective functions in optimization procedure. There are many criteria which tell the differences between analytical and experimental results. In conventional model updating study, they are combined into a single-objective function using weighting factors [3]. Thus, these criteria are forced to compare to each other, although they are physically incompatible in nature. There are no general rules for selecting the weighting factors since they do not proportionally reflect the relative importance of the criteria. Thus, a necessary approach is to solve the same problem repeatedly by varying the values of weighting factors until a satisfactory solution is obtained. But, due to the inherent defects of the weighting method, it usually takes very much time to finally obtain satisfactory weights [4–6]. This makes model updating practices difficult. In this work, multiobjective or multi-criteria optimization technique is introduced to avoid the difficulty in conventional model updating and to evaluate the error criteria as they are. Especially, an interactive multiobjective optimization technique called satisficing trade-off method is used for its effectiveness [6–8].

The success of finite element model updating also depends on the selection of updating parameters. In this work, an automated parameter selection procedure is applied to select the updating parameters after locating modeling errors in the FE model [5,9].

In the first part of this paper, an interactive multiobjective optimization technique based on aspiration level is introduced. Its effectiveness will be explained in comparison with the conventional weighting method. The second part presents a model updating procedure, which seamlessly incorporates the interactive multiobjective optimization and the automated parameter selection procedure. Finally, the model updating procedure is tested for the FE model updating of a real complex structure.

2. Interactive multiobjective optimization

This section describes some important concepts related to multiobjective optimization, and the benefits of multiobjective optimization in comparison with single-objective optimization in model updating. Among various multiobjective optimization methods, an interactive multiobjective optimization technique called satisficing trade-off method is introduced for its effectiveness.

2.1. Basic concepts

A multiobjective optimization problem (**MOP**) is formulated as follows [8]:

$$\begin{aligned} &\text{minimize} \quad \vec{F}(\vec{x}) = \{F_1(\vec{x}), F_2(\vec{x}), \ldots, F_r(\vec{x})\} \\ &\quad \text{subject to} \quad F_i(\vec{x}) \le \overline{F}_i, \quad i = r+1, \ldots, s, \\ &\qquad \vec{x} \in \vec{R}^n, \end{aligned} \tag{1}$$

where $F_1, \ldots, F_s$ are the criteria or objective functions which designate differences between analytical and experimental results. $\overline{F}_i$ is called the aspiration level of F_i. In general, MOP gives a set of solutions called Pareto optimal set [10].

Definition 1. A feasible vector $\hat{\vec{x}}$ is a **Pareto optimal** for (1) if and only if there exists no feasible vector $\vec{x}$ such that for all $i = 1, \ldots, r$

$$F_i(\vec{x}) \le F_i(\hat{\vec{x}}), \tag{2}$$

and for at least one $i \in \{1, 2, \ldots, r\}$

$$F_i(\vec{x}) < F_i(\hat{\vec{x}}). \tag{3}$$

Mathematically, every Pareto optimal point is an equally acceptable solution of the MOP. Selecting one out of the set of Pareto optimal solutions calls for information that is not contained in the objective functions. A decision maker is needed to make the selection. The **decision maker** (**DM**) is a person (or a group of persons) who has better insight into the problem and who can express preference relations between different solutions. During solution processes, various kinds of information are required from the DM. Such items of information may include, for example, desirable or acceptable levels in the values of the objective functions. These objective values (whether feasible or not) are of special interest and importance to the DM [10].

Definition 2. Objective function values that are satisfactory or desirable to the decision maker are called **aspiration levels** and denoted by $\overline{F}_i, \; i = 1, \ldots, s$. The vector $\overline{\vec{F}}$, consisting of aspiration levels, is called a **reference point**.

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