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ROBUST UPDATING OF UNCERTAIN COMPUTATIONAL MODELS FROM EXPERIMENTAL MODAL DATA

Capiez-Lernout E.[1,*], Soize C.[1], Ohayon R.[2],

[1] Universite Paris-Est, Laboratoire de Mecanique,
5, Bd Descartes, 77455 Marne-la-Vallee, France
evangeline.capiezlernout@univ-paris-est.fr
christian.soize@univ-paris-est.fr

[2] Conservatoire National des Arts et Metiers,
Structural Mechanics and Coupled Systems Laboratory,
2, rue Conté, 75003 Paris, France
roger.ohayon@cnam.fr

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ABSTRACT

It is well known that the role played by modal analysis in structural engineering is very important. The computational models developed in structural dynamics have to accurately predict the dynamical behaviour of the complex dynamical systems. It is then necessary to update these computational models by optimizing an objective function describing the quality of the computational model with respect to the experiments. One strategy consists in using experimental modal analysis. In general deterministic updating formulations are proposed, which means that the computational model which has to be updated is a deterministic computational model. Robust updating is then defined as the updating of an uncertain computational model which takes into account both model and data uncertainties. This means that the uncertain computational model which has to be updated is constructed in introducing a probabilistic model of uncertainties. It should be noted that such a robust updating formulation has been proposed in [1,2] for the case of available experimental frequency response functions.

The present work concerns the robust updating of an uncertain computational model using experimental modal analysis. The formulation of this robust updating problem is based on the deterministic updating strategy proposed in [3,4] and which is used for calculating the initial value $\mathbf{r}^\star$ for the robust updating problem. One has

$$\mathbf{r}^\star = \arg \min_{\mathbf{r} \in \mathcal{R}} \underline{j}(\mathbf{r})$$

in which $\mathcal{R}$ is the admissible set of the vector-valued updating parameter $\mathbf{r}$ of the deterministic computational model. The objective function is defined as $\underline{j}(\mathbf{r}) = \underline{\rho}^2(\mathbf{r})$ in which $\underline{\rho}(\mathbf{r})$ is a residue defined

from the experimental eigenfrequencies and eigenmodes and from the operators of the computational model such that $\underline{\rho}(\mathbf{r}) = ||[\underline{\Phi}^{\exp}]^T\,[\underline{R}(\mathbf{r})]||_F$ with

$$\begin{bmatrix} [\underline{R}(\mathbf{r})] \\ [0] \end{bmatrix} = [\underline{K}(\mathbf{r})] \begin{bmatrix} [\underline{\Phi}^{\exp}] \\ [\underline{\Phi}(\mathbf{r})] \end{bmatrix} - [\underline{M}(\mathbf{r})] \begin{bmatrix} [\underline{\Phi}^{\exp}] \\ [\underline{\Phi}(\mathbf{r})] \end{bmatrix} [\underline{\Lambda}^{\exp}] \tag{1}$$

One then constructs a mean reduced matrix model by using the Craig-Bampton substructuring method. The uncertain computational model is constructed with the non-parametric probabilistic approach by replacing the mean reduced matrices by random matrices for which the probability distributions are explicitely known [5,6]. In this class of stochastic computational model, the vector-valued updating parameter is denoted by $\mathbf{s} = \{\mathbf{r}, \boldsymbol{\delta}\}$ in which the vector-valued updating parameter $\boldsymbol{\delta}$ describes the amount of uncertainty in the system. The objective function $j(\mathbf{s})$ is then defined as $j(\mathbf{s}) = E\{\boldsymbol{\varrho}^2(\mathbf{s})\}$ with $\boldsymbol{\varrho}(\mathbf{s}) = ||[\boldsymbol{\mathcal{R}}(\mathbf{s})]||_F$ in which the matrix $[\boldsymbol{\mathcal{R}}(\mathbf{s})]$ is defined as a function of the random matrices and of the experimental modal data. Two cases are then considered. If the level of uncertainty $\boldsymbol{\delta}$ is known, the solution of the inverse problem allowing the uncertain computational model to be updated is given by

$$\mathbf{s}^* = \arg\min_{\mathbf{s}\in\mathcal{S}} j(\mathbf{s}) \quad , \tag{2}$$

in which $\mathcal{S}$ is the admissible set defined for updating parameter $\mathbf{s}$. If the level of uncertainty $\boldsymbol{\delta}$ is unknown, the optimization problem defined by Eq. (2) is not well defined because the solution would tend to a deterministic solution. For a given scalar $\alpha \in [0,1]$, one then introduces a probabilistic constraint $g_\alpha(\mathbf{s},\epsilon) < 0$ in which $g_\alpha(\mathbf{s},\epsilon)$ depends on a given probability level α and on a scalar ϵ which quantifies the improvement with respect to the deterministic updating. The inverse problem allowing the uncertain computational model to be updated consists in minimizing cost function $j(\mathbf{s})$ with this additional constraint. Finally, the metholodology is applied on a numerical example constituted of bars and beams forming a truss, for which the first experimental eigenvalues and the first experimental eigenmodes measured at several locations are given.

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