ONLINE LOCAL STRUCTURAL HEALTH MONITORING USING THE SUBSTRUCTURE ISOLATION METHOD[1]

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1. Introduction

This paper proposes a Substructure Isolation Method (SIM) for online local health monitoring at the substructural level. The SIM [1] includes two key steps: isolation of the substructure, and its local identification. Isolated substructure is an independent virtual structure, which is isolated from the global structure with virtual supports placed in the interface DOFs. Its response is constructed by such a linear combination of time series of measured local responses that the desired boundary conditions are satisfied and all outside influences are removed. Given the combined response, the substructure is locally identified using any of the standard methods aimed originally at global analysis. This is unlike other substructuring methods, see e.g. [2,3], which require dedicated methods in order to deal simultaneously with structural damages and generalized interface forces.

The SIM has been originally [1] used in off-line analysis and required zero initial conditions. Here, it is used for local online monitoring by a repeated application to successively extracted measurement time series. Non-zero initial conditions are allowed; they are reflected in a free vibration component of the constructed responses of the isolated substructure.

2. Sensors, excitations and measurement time series

The substructure is virtually isolated from the global structure by placing virtual supports in all its interface DOFs. These supports are implemented by physical interface sensors x_i, $i=1,\ldots,I_B$, and used for the purpose of isolation only. Besides, there are I_S internal sensors y_i, $i=1,\ldots,I_S$, which are placed inside the substructure in order to measure its response. The isolation process consists of altering the readings y_i of the internal sensors (using the reading of the interface sensors x_i) in such a way that the result equals their reading *as if* they were placed in a physically isolated substructure.

Here, no intentionally applied excitations of the substructure are considered. That is, the sensors measure only its free response to operational excitations occurring in the outside structure, such as wind, traffic, modal hammer, running engines, etc.

For the purpose of online monitoring, it is assumed that the responses x_i and y_i are measured continuously. The time series measured this way $\{x_i(t_k)\}_k$ and $\{y_i(t_k)\}_k$ are divided into N successive and possibly overlapping time sections each of length K, $\mathbf{x}_i^n = \{x_i^n(t_k^n)\}_{k=1,\ldots K}$ and $\mathbf{y}_i^n = \{y_i^n(t_k^n)\}_{k=1,\ldots K}$, where k indexes the time steps anew within each section, n is the number of the time section and $t_1^{n-1} < t_1^n < t_1^{n+1}$ for all n. In each time section, the readings of all the interface sensors $\mathbf{x}_i^n$, $i=1,\ldots,I_B$, are combined into a single interface response vector $\mathbf{X}^n$. The readings of all the internal sensors $\mathbf{y}_i^n$, $i=1,\ldots,I_S$, are combined into a single internal response vector $\mathbf{Y}^n$, too.

3. The combined response and isolation

Assume that the measurement vectors $\mathbf{X}^n$ and $\mathbf{Y}^n$ for $n=1, \ldots, N+1$ are extracted from the measured time series and available. Consider the following combined response vectors:

(1) $$\mathbf{C}_\mathbf{X} = \mathbf{X}^{N+1} + \sum_{n=1}^{N} \alpha_n \mathbf{X}^n = \mathbf{X}^{N+1} + \mathbf{X}\boldsymbol{\alpha}, \qquad \mathbf{C}_\mathbf{Y} = \mathbf{Y}^{N+1} + \sum_{n=1}^{N} \alpha_n \mathbf{Y}^n = \mathbf{Y}^{N+1} + \mathbf{Y}\boldsymbol{\alpha}$$

[1] Proc. of the 38th Solid Mechanics Conf. (SolMech'2012), 27-31 August 2012, Warsaw, Poland, pp. 306-307.

where the vector $\boldsymbol{\alpha}$ collects is combination coefficients α_n, and $\mathbf{X}$ and $\mathbf{Y}$ are matrices composed of column vectors $\mathbf{X}^n$ and $\mathbf{Y}^n$. If the substructure is assumed to be linear, the combined response vectors $\mathbf{C}_\mathbf{X}$ and $\mathbf{C}_\mathbf{Y}$ are its valid responses (solutions to its equation of motion), and they can be thus used for monitoring. Moreover, if the combination coefficients are selected in such a way that the combined interface response vanishes,

(2) $$\mathbf{C}_\mathbf{X} = \mathbf{X}^{N+1} + \mathbf{X}\boldsymbol{\alpha} = \mathbf{0}, \qquad \boldsymbol{\alpha} = -\mathbf{X}^{-1}\mathbf{X}^{N+1},$$

then the corresponding combined internal response vector $\mathbf{C}_\mathbf{Y}$**,**

(3) $$\mathbf{C}_\mathbf{Y} = \mathbf{Y}^{N+1} - \mathbf{Y}\mathbf{X}^{-1}\mathbf{X}^{N+1},$$

is the response of the isolated substructure (the actual substructure, *as if* it was physically isolated from the outside structure).

4. Online local structural health monitoring

The response $\mathbf{C}_\mathbf{Y}$ of the isolated substructure can be used with any general SHM approach aimed originally at global monitoring [4]. Online monitoring is possible by repetitive (1) updating of the set of N time sections used to construct $\mathbf{X}^n$ and $\mathbf{Y}^n$ with new measurements, (2) application of the SIM to the updated set, and (3) application of an SHM method to the constructed response.

5. Numerical and experimental examples

The isolation approach was verified experimentally using an aluminum cantilever beam and a virtual pinned support, which was implemented by a transverse velocity sensor and a strain sensor. The damage was identified by fitting the natural frequencies of the modeled substructure [5] to the identified frequencies of the isolated substructure [6]. Due the space constraints of this abstract, the results will be presented during the conference.

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6. References

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