OFF-LINE RECONSTRUCTION OF DYNAMIC LOADS

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1. Introduction

This research considers off-line reconstruction of spatial and temporal characteristics of dynamic loads in linear and elastoplastic systems. The motivation is the need for a technique for efficient a posteriori identification of the scenario of a sudden load, to be applied in black-box type systems.

There is an ongoing research effort in the field, see e.g. [2] for a relatively recent review. However, the structures are usually assumed to be linear and the generality of the considered loads is limited to a single pointwise load with the location known in advance or determined in an additional nonlinear optimization. Moreover, the reconstruction is often simplified by assuming stationarity of the load. If a moving force is considered, it has a constant velocity. A number of papers deals with single pointwise impact loads only and disregards all load characteristics besides the location. Papers that do consider multiple independent loads, assume superfluous number of sensors.

The approach proposed here is aimed at the fully general case. In the so-called underestimated case it allows to use a limited number of sensors to reconstruct general dynamic loads of unknown locations, including simultaneous multiple impacts, freely moving and diffuse loads. However, this is at the cost of the uniqueness of reconstruction, which can be attained only with additional heuristic assumptions. This way an equivalent load is identified, which is observationally indistinguishable from the actual load and optimum in a given sense. Additionally, the problem of optimum sensor location is discussed.

2. Response to dynamic load and load reconstruction

At zero initial conditions, the discretized response $\boldsymbol{\varepsilon}$ of a linear system can be expressed by means of a simple convolution equation $\boldsymbol{\varepsilon} = \mathbf{B}\mathbf{p}$, where the vector $\mathbf{p}$ collects the discretized loads in all load-exposed degrees of freedom (DOF) and $\mathbf{B}$ is the system transfer matrix. The elastoplastic behavior is included by combining the Virtual Distortion Method (VDM) [1] with the return mapping algorithm. The convolution equation takes into account the effects of the plastic distortions $\boldsymbol{\beta}$ of the yielding elements, $\boldsymbol{\varepsilon} = \left[\mathbf{B}\,\mathbf{B}^{\mathrm{P}}\right]\left[\mathbf{p}^{\mathrm{T}}\,\boldsymbol{\beta}^{\mathrm{T}}\right]^{\mathrm{T}}$. The distortions $\boldsymbol{\beta}$ have to satisfy the constitutive law and are nonlinearly dependent on the unknown load $\mathbf{p}$ [3]. Load reconstruction amounts to a deconvolution: compare the measured $\boldsymbol{\varepsilon}^{\mathrm{M}}$ and the modeled $\boldsymbol{\varepsilon}$ system responses, and obtain the excitation by solving the resulting system of equations. For a linear system, it leads to a large and intrinsically ill-conditioned system of linear equations, while an elastoplastic system yields nonlinear equations.

If the system is linear overdetermined, a unique load can be found relatively easily. In underdetermined linear systems, the unknown load can be split into two complimentary components: the reconstructible component which can be reconstructed from the measurement, and the unreconstructible component. All information about the latter is lost in the measurement process, hence it cannot be reconstructed, but can be assumed using heuristic postulates. In an elastoplastic system, three cases are possible: strongly overdetermined case, in which there are more sensors than load-exposed DOFs and yielding elements, overdetermined case and underdetermined case, in which there are fewer equations than unknowns. In the strongly overdetermined case, the load $\mathbf{p}$ and the distortions $\boldsymbol{\beta}$ can be treated as uncoupled; the resulting equation can be considered linear and solved directly. The other two cases lead to nonlinear problems, which can be solved by gradient-based optimization techniques.

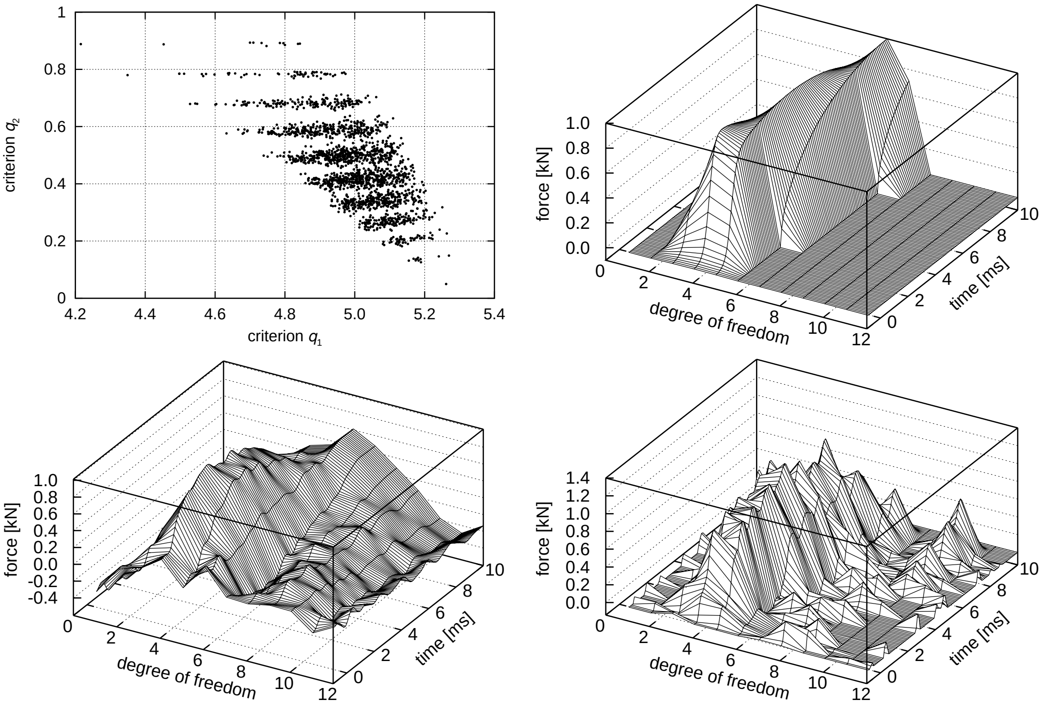

Figure 1. Numerical example: (top left) correlation plot for the two proposed sensor location criteria. Each dot corresponds to one of 2047 considered locations of 1 to 11 sensors; (top right) assumed actual load evolution; (bottom left) identification result for the linear system, four sensors and 5 % rms noise level; (bottom right) identification result for the elastoplastic system, five sensors and 5 % rms noise level

3. Optimum sensor location

Optimum sensor location is crucial for the accuracy of the reconstruction. Two sensor location criteria are proposed, based either on the dimension of the unreconstructible load subspace or on its coincidence with a given set of expected or typical loads. These criteria tend to be negatively correlated, thus a third, compound criterion is proposed, which can be seen as a single *a priori* measure of reconstruction accuracy.

4. Numerical example

In the numerical example a 119 element truss structure is used. There are 100 measurement time steps (of 0.1 ms) and 110 reconstruction time steps. Since 12 DOFs are load-exposed and four (or five) sensors are used, the resulting system is a strongly underdetermined (1320 unknowns and 400 or 500 equations). The assumed testing load and the results are shown in Figure 1.

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[2] E. Jacquelin, A. Bennani, P. Hamelin (2003), Force reconstruction: analysis and regularization of a deconvolution problem, *Journal of Sound and Vibration*, **265**, 81107.

[3] Ł. Jankowski (2008), Off-line identification of dynamic loads, *Structural and Multidisciplinary Optimization*, in press.