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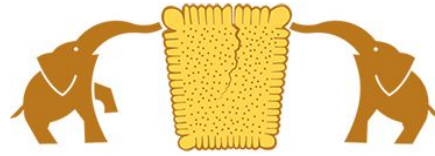
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## Optimizing camera position for the modal analysis of a 3D structure

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**Abstract** — Full-field kinematic measurements with one or several high-speed cameras is a promising non-invasive technique for the modal analysis of civil engineering structures. It raises however the question of the positioning of the cameras for an optimal geometric characterization of the mode shapes of interest. We address this question on a simplified model, from both experimental and numerical points of view. Standard perspective projection equations are first used. A mode-visibility criterion is proposed and illustrated for two modes and positions. Possible enrichments of the criterion are discussed.

**Keywords** — Structural vibration, modal analysis, digital image correlation, pinhole projection

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**Introduction** For several decades, vibration-based methods for damage detection in mechanical structures have been significantly developed, due to the need for health monitoring of increasingly light and slender constructions. Full-field kinematic measurements with high-speed cameras is a promising non-invasive alternative to more classical sensor-based approaches. While its applicability has already been demonstrated for simpler 2D structures such as a beam [1], its extension to more complex 3D ones rises the question of the optimal positioning of the cameras. Indeed a single camera provides only some 2D projection of the motion. A better characterization of the dynamic response of the structure, and of its evolution which is the signature of damage, raises then the question of the best positioning of one or more cameras, to improve the accuracy of the identified mode shapes. To address this question a laboratory model is considered here, from both the experimental and numerical points of view, to construct and validate a visibility criterion of the mode shapes that might be used in more complex situations.

**Methods** The test is carried out on a beam structure composed of a hollow steel beam of square section and a threaded steel rod (fig 1.a). Such a structure exhibits low frequency modes for which the displacements are relatively large and will therefore be easily observable by the camera (apparent displacement larger than one pixel), and higher order modes with smaller displacements (amplitude of the order of one pixel or less) which will allow to account for the accuracy of the measurements by the camera. The projection model chosen for the camera in the numerical simulation is the classical pinhole one [2].

The modal analysis of the structure (fig. 1(a)) is performed using the ABAQUS FE software, which provides the natural frequencies and the associated modal shapes. Mass and stiffness matrices are extracted to carry out time-domain simulations with Matlab for which the first ten eigenmodes are considered. The structure is subjected to a shock applied to an edge, with an orientation chosen so as to excite all modes of the structure. Many camera configurations (position and orientation) are defined around the structure as illustrated in figure 1(b). The FE nodes visible by the camera for each configuration are extracted together with their ten modal displacements. Then, the projected image of the 3D structure is reconstructed (figure 2 (a) and (c)) for each configuration using the camera intrinsic and extrinsic parameters.

A first quantification of the local visibility of the mode shape at some point  $P$  of the structure is obtained by projecting the modal displacement at this point onto the plane normal to the  $CP$  line, where  $C$  is the camera pinhole. Indeed the component of the displacement along this line is not visible by the camera, at least in the small strain formalism.

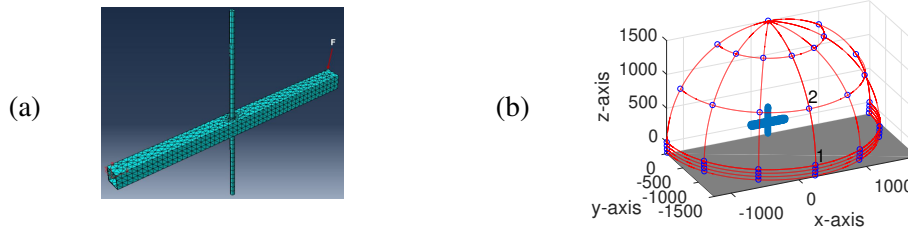


Figure 1: (a) 3D model in ABAQUS, (b) Camera positions

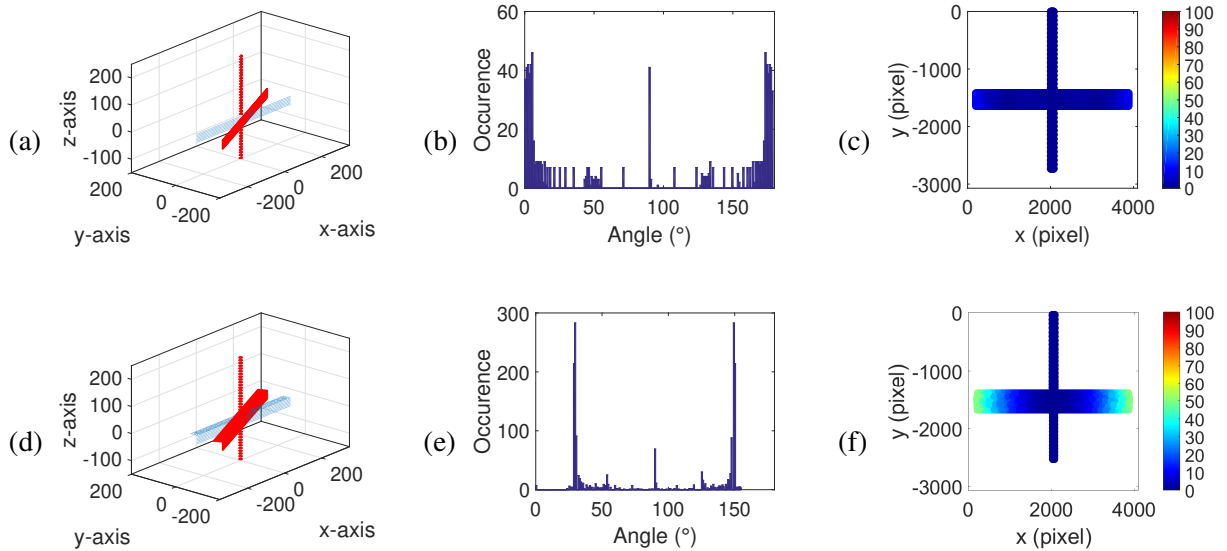


Figure 2: (a)(d) 2<sup>nd</sup> mode shape for visible nodes, (b)(e) Angle occurrences, (c)(f) Visibility criterion

**Results** The considered camera positions are located in front of the structure and inclined at  $30^\circ$  along the X-axis. For this preliminary work, the analysis focuses on the second mode which is a torsional mode with a natural frequency of 20.1 Hz. Figures 2(c) and (f) provide the map of the local visibility for this mode for the two camera positions. This local visibility depends on both the local angle between CP and modal displacement (fig. 2(b) and (e)) and the amplitude of the latter, both varying over the structure. The integration of this local mode visibility over the image of the structure provides a scalar quantification of its global visibility by the camera, which can be optimized to determine the best position for the chosen mode. For the camera configurations and mode shape studied, the maximum displacement is located at the ends of the beam, therefore the visibility criterion is maximum at those nodes.

**Discussion and Perspectives** The proposed criterion clearly allows to distinguish camera positions in terms of their ability to observe some vibration modes. It still needs to be improved to better reflect the whole sets of parameters which determine the accuracy of the optical measurement of vibration modes. In addition to the local angle and amplitude, the local orientation of the observed surface, with respect to both the camera and the lighting, which determines how patterns are rendered in the image and how well image correlation algorithm might operate, and the local depths of field of the image (in relation to the chosen aperture) might also be considered in the criterion. The quantitative combination of visibility criterions for several modes and/or several camera positions is another open question.

## References

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