Comparative study of the first bending modes of a cantilever beam from a video measurement

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Abstract
In the field of rotating machinery diagnostics, this paper presents a case study on the mode reconstruction and modal analysis of an embedded-freestanding beam using a high-speed camera. The results obtained are compared to those obtained with a LDV (Laser Doppler Vibrometer). This study provides a better understanding of the advantages and limitations of using high speed cameras in the modal analysis of mechanical structures.

1 Introduction

High-speed cameras are gaining popularity in machine diagnostics due to their spacial precision and non-invasiveness in analyzing moving structures. However, the use of these cameras for reconstructing the natural modes of structures is still limited. This document presents an experimental study aimed at reconstructing the natural modes of a clamped-free beam using a high-speed camera. The study assesses the feasibility of this method by comparing the results to those obtained from a laser vibrometer.

Figure 1: Cantilever beam

2 Methodology

The image preprocessing steps are shown in Figure 2. Starting from the raw image, there are a total of five steps.

Figure 2: Image processing steps

Once the images are processed (see Fig. 3), the estimation of the neutral fiber of the beam is performed by calculating the centroid for each column of the image.

A mode shape is characterized by its natural frequency, damping ratio, and modal shape. These three parameters are what we aim to extract from the video in this case.

Figure 3: Processed image

The natural frequency is estimated using the peak-picking method. The modal damping is estimated in two steps: first, the Impulse Response Function (IRF) is estimated thanks to the NExT method [2], and then an interpolation is performed between the IRF and a decaying exponential. Finally, the modal shape is estimated by temporally filtering the video at the previously obtained natural frequencies.

3 Results

The natural frequencies are obtained using the peak picking method proposed by Liutkus [1]. The results are summarized in Table 1.

Mode number	Frequency - LDV (Hz)	Frequency - Video (Hz)	Damping - LDV	Damping - Video
1	6.6	6.5	0.59	0.67
2	39.4	39.4	0.68	0.71
3	109.1	108.9	0.70	0.69
4	215.3	214.9	0.69	0.70
5	355.9	355.7	0.70	0.70
6	533.7	533.8	0.71	0.70

Table 1: Natural frequencies and damping

The frequencies obtained from the video are 1% lower for modes 1 to 5. However, it should be noted that the frequency precision of the laser vibrometer is 0.325 Hz. This precision can be improved by applying zero-padding to the signal. Therefore, the first six modes can be effectively observed using the high-speed camera. The absolute difference of the dampings $|\zeta_{vib} - \zeta_{vid}|$ is less than 0.03 for modes 2 to 6. The difference in the obtained damping values for the first two modes can be justified by the distinct frequency accuracy of the two measurement methods.

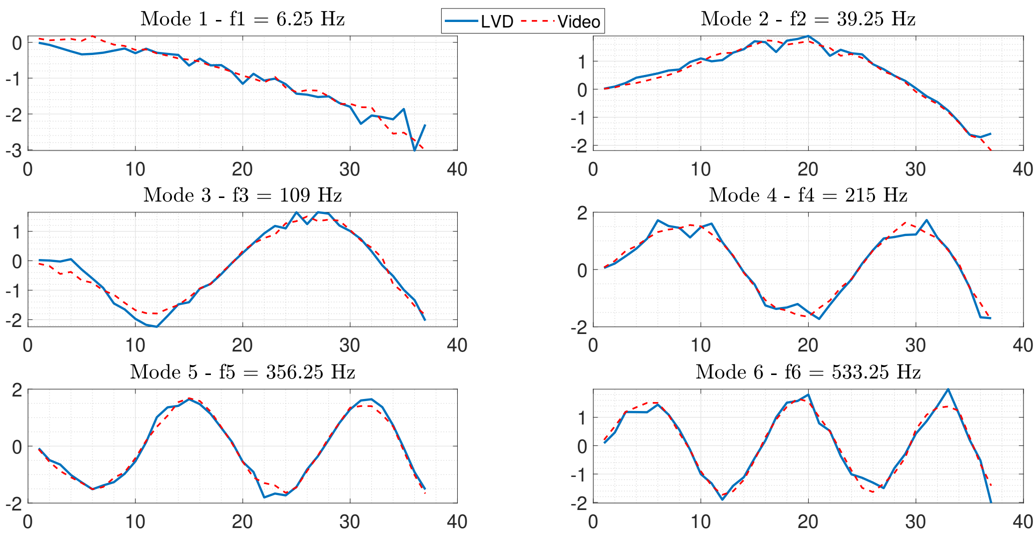

Figure 4: Modal shapes

Once the modal shapes are obtained and spatially aligned (see Fig. 4), the Modal Assurance Criterion

(MAC) matrix between the video and the laser vibrometer is calculated. The results are presented in Figure 5.

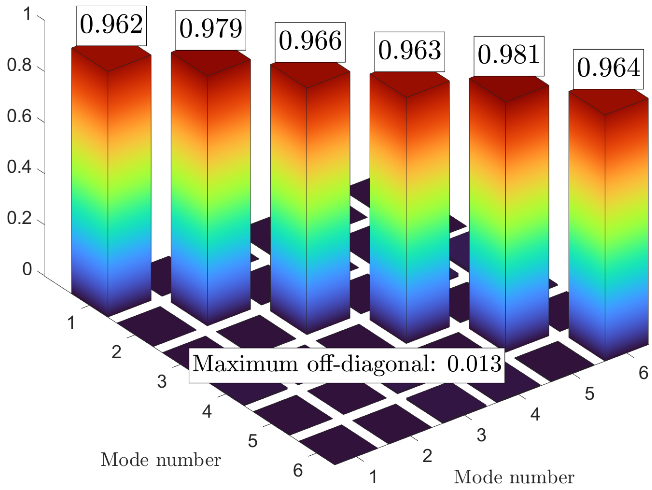

Figure 5: crossMAC between video and LDV

For a threshold of 0.95, the first six bending modes can be accurately reconstructed from the video acquisition.

4 Discussion

The obtained results demonstrate that it is possible to reconstruct vibration modes using a video camera. However, it is important to acknowledge that these results can be affected by various measurement parameters. One significant parameter is resolution, which determines the number of pixels needed to capture an image. It directly impacts the processing time of the algorithms employed. The frame rate plays a crucial role as it determines the number of observable modes. Lighting conditions, which affect the quality of the image, also have an influence on the analysis. The presented preprocessing techniques can help mitigate this issue. Therefore, it is crucial to carefully understand and select the measurement parameters to optimize them for accurate and reliable outcomes. Moreover, this method assumes that there is visual access to the specific part of the machine that needs to be filmed, which can be more challenging in certain cases. Additionally, a frontal view is required.

5 Conclusion

A feasibility study was conducted to reconstruct the first bending modes of a clamped-free beam using a high-speed video camera. The objectives were to demonstrate the relevance of such a method for structural vibration analysis. Future prospects include the use of smartphones to capture high-frequency video footage and the improvement of data analysis for increased accuracy. This method of reconstructing vibration modes on rotating machinery for monitoring and diagnostics shows promising potential and warrants further exploration.

References

[1] Liutkus, A. , *Scale-Space Peak Picking*, Inria Nancy - Grand Est (Villers-lès-Nancy, France), 2015

[2] James, III, G. H. and Carne, T. G. and Lauffer, J. P. , *The Natural Excitation Technique (NExT) for modal parameter extraction from operating wind turbines*, 1993