Hilbert Video Magnification for Structures under Normal Variability

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***Abstract*— This work assesses the performance of a video-based motion magnification algorithm to extract natural frequencies, mode shapes. The technique combines the Hilbert Transform, Principal Component Analysis (PCA), and Blind Source Separation (BSS) to identify and analyze vibration modes of structures. The study examines the effectiveness of this approach in real-world scenarios, where environmental and operational variability are present. These changes may negatively influence the modal decomposition process if the video-based technique is not robust. Despite these challenges, the analyzed method demonstrates proper performance in decomposing structural vibrations, highlighting its potential for practical applications in structural health monitoring.**

***Keywords*— Hilbert Transform, Dimension Reduction, Computer Vision, Environmental Variability, Operational Variability.**

I. Introduction

Modal analysis is an essential tool for structural dynamics and vibration analysis, extracting dynamic characteristics such as natural frequencies, mode shapes, and damping ratios. It provides insights into the behavior of mechanical systems and civil structures under various loading conditions, aiding in vibration testing, structural health monitoring, dynamics modification, and vibration control [1]. Nevertheless, the application of video measurements for the blind identification of full-field vibration modes has emerged as a significant advancement in structural dynamics and modal analysis [2-5]. These techniques allow for the extraction of detailed vibration patterns and modal behavior without the need for prior knowledge of the structural dynamics. However, techniques based on the application of phase-based optical flow limit a practical use as it needs the manual definition of filters for motion extraction. On the other hand, strategies based on the estimation of complex modes from video measurements using the Hilbert transform (HT) have become a promising option, as the motion is encoded in the imaginary component of the analytical signal, disregarding the need for manual filter definition [3].

In non-ideal scenarios, videos often contain operational and environmental variability, such as moving parts, non-stable background, vegetation and wind, which can reduce the efficiency of such techniques. In this work, we evaluate the performance and robustness of the Hilbert motion magnification algorithm to decompose structural modes from video recordings with the presence of varying normal conditions. We found that the algorithm can proper decompose individual modes, indicating its application for real-time, autonomous vibration monitoring.

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II. Video-Based blind Identification of modes

In this work, we assess the effectiveness of the technique proposed in [3] for identifying structural modes, notwithstanding the presence of operational and environmental variability.

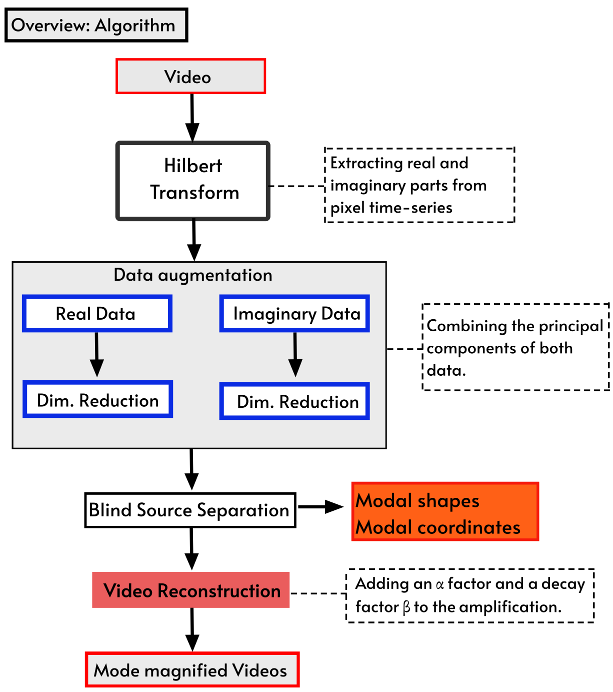

Fig. 1: Steps in the Hilbert motion magnification with data augmentation.

According to Fig. 1, the steps proceed as follows: the real and imaginary part of the analytical signal are extracted after applying the HT. Then, the data is reduced using the principal components analysis algorithm, extracting the principal components (PC) of both sets of data. Subsequently, the PC of both signals are combined to determine a new set of data to be worked on. At this point we apply blind source separation (BSS) on the basis of complexity pursuit [5] to extract the individual modal responses from the video data. In video-based structural dynamics, BSS interprets structural vibrations

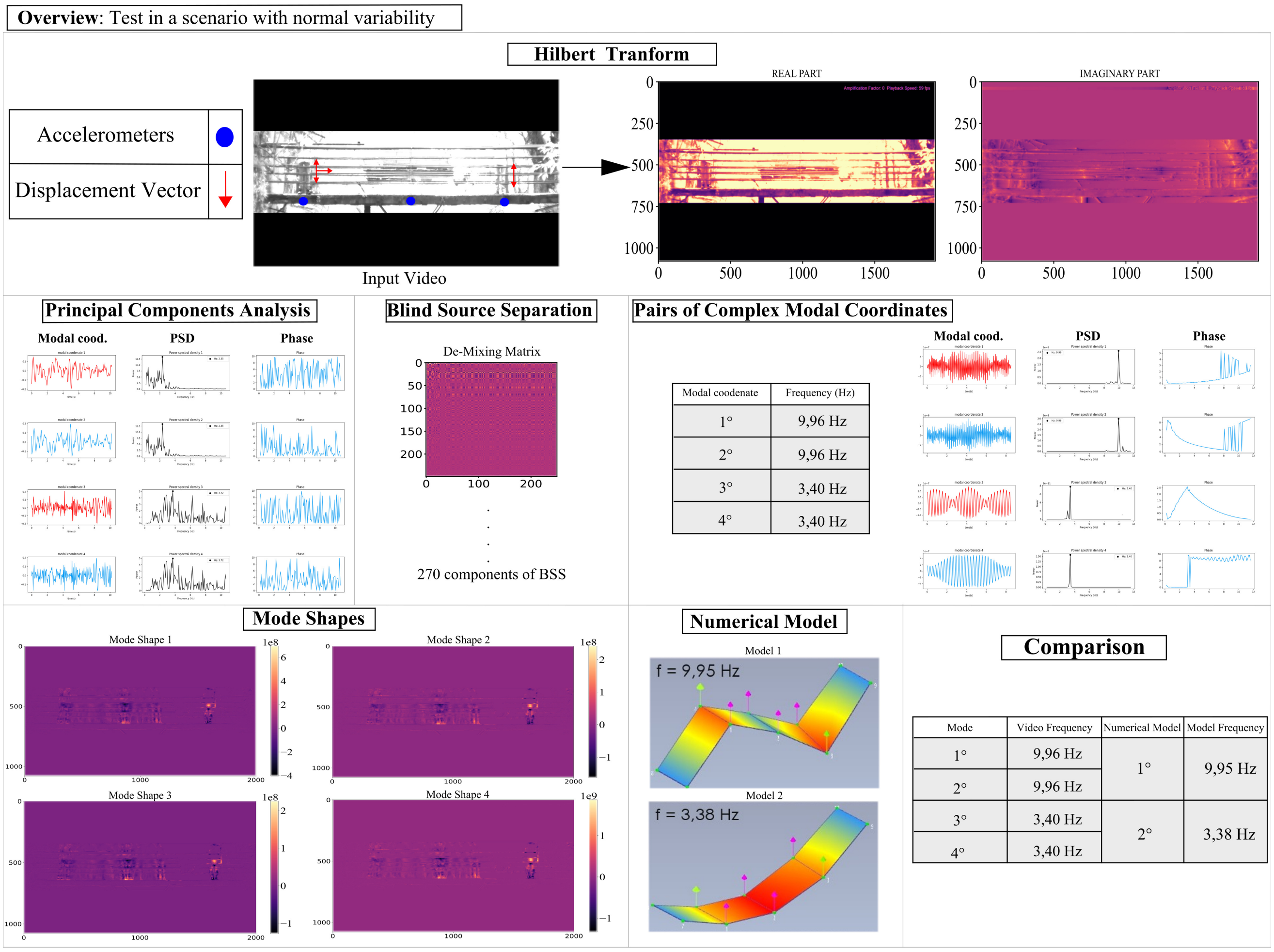

Fig. 2: Overview of the proposed technique applied in the test setup featuring an Iris M - RDI camera positioned 90 meters away, recording at a consistent frame rate of 59 fps.

within video frames as localized, time-varying motions encoded into the pixel time-series [2][4][5]. The end result are pairs of modal coordinates and mode shapes representing the real and imaginary components of a complex mode, from which we can reconstruct individual motion magnified videos by adding a scaling factor α and a decay β [4].

III. Analysis and Conclusions

Figure 2 illustrates the implementation of the technique in a scenario featuring normal variability, with two people performing movements on the footbridge, along with other motion artefacts such as wind-induced tree movement. The focus is on analyzing the modal frequency of the footbridge, comparing it with a numerical model built in the Artemis software, which does not rely on a finite element model.

From out tests, a discrepancy of just 0.01 Hz was observed between the first and second complex coordinates of the algorithm in relation to the frequency extracted from the numerical model, while a difference of 0.02 Hz was recorded between the third and fourth coordinates, indicating close match between the numerical model and the video-based technique estimations. This suggests the algorithm is robust to filter out motion from normal variations from the modal responses of the structure, indicating its reliable application for operational modal analysis.

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