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Methods and algorithms for video-based multi-point frequency measuring and mapping

David Mas [a,*], Belen Ferrer [b], Pablo Acevedo [a], Julian Espinosa [a]

[a] *Univ. Inst. Physics Applied to Sciences and Engineering, University of Alicante, PO Box, 99, 03080 Alicante, Spain*
[b] *Dept. Civil Engineering, University of Alicante, PO Box, 99, 03080 Alicante, Spain*

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ABSTRACT

Object vibrations and movements can be detected through changes in its luminance. In this paper, we demonstrate that we can obtain the vibration frequency of all vibrating targets in the sequence simultaneously through the analysis of local neighborhoods. The study is completed with a short-time Fourier analysis so that changes in the movement frequencies are also accounted. We also show that this information can be displayed like a color frequency map that can be superimposed to the video sequence providing a whole description of the analyzed sequence. The method can be used to analyze complex structures since their different vibrating parts can be visualized at a glance. The main algorithms, methods and some sequences are freely downloadable so that new applications and procedures can be implemented by the scientific community.

1. Introduction

Movement detection and frequency measurements are of great importance in many fields including Physics and Engineering. Contact sensors are often preferred and, among them, accelerometers are the most used for vibration monitoring. Although their really good performance, in some occasions the complexity or accessibility of the specimen to be measured increases the installation cost and may be even hazardous for the test crew safety. Because of this, non-contact methods such as laser vibrometers are becoming more popular and are being applied to new fields [1]. Nevertheless, their high cost is still a big drawback that restricts their use to only some particular cases.

Computer vision systems have been demonstrated to be a reliable alternative to traditional methods. In the last years, thanks to the decreasing prices of high-speed cameras together with the increased capabilities of storage systems and computers, several proposals, methods and applications have appeared in several areas such as Biomedical Sciences, Surveillance or Civil Engineering [2–14]. With independence of the application area or the proposed method, the common hypothesis of these papers is that object movement can be perceived through changes in the light reflected or diffused by a moving target.

In Refs. [8–10], the authors use object recognition techniques in order to determine the vibration of different structures. Although these methods provide accurate results, they require of high contrast images in order to facilitate the image analysis and also tend to be very demanding in computational time and resources. Vibration measurement techniques without object recognition have been also proposed in the literature. In [11], the authors analyze video sequences of objects placed close to a loudspeaker. Video analysis is done through decomposition of the video signal into the local spatial amplitude and phase using a complex-value steerable pyramid filter bank [12]. Through image analysis they are able to speech capturing

* Corresponding author.
E-mail address: david.mas@ua.es (D. Mas).

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and recognition even through acoustically isolating windows. The method does not require that the vibrating surface be specular, diffusive or fulfill any special property to obtain a reliable signal. The obtained impacting results received much attention from public and media. The same approach has been used later by some of the authors to magnify the motion of simple structures and facilitate the modal identification and analysis [13]. Unfortunately, the algorithm presented requires complex image transformations and may result in a slow and heavy algorithm. This problem was later addressed in [14]. There, the authors present a reformulation of the idea in terms of image correlation. They claim that their method is much faster than the original one and is able to resolve movements up to 0.16 px on the CCD sensor. Although this may seem a minor detail, resolutions below the pixel limits are of fundamental importance for measuring small vibrations or from far distances. It results evident that large movements can be easily detected by noticeable changes in the image. On the contrary, small amplitude movements are not so easy to detect since changes in the image will be subtle and affect to very few unconnected pixels. Therefore, reliable methods for vibration measurements need to achieve sub-pixel resolutions.

In [15], the authors demonstrated the possibility of measuring the vibration frequency of objects in a high-speed video sequence just by counting luminance changes in local regions. The object does not have to fulfill any specific requirement and no especial feature is detected or matched. Although the method may not be as fast as the one proposed in [14], it is able to measure oscillation amplitudes of 0.013 px, as we will show below. This means an improvement of one order of magnitude with respect to similar papers cited above without performing any interpolation or image transformation. Additionally, the method is developed without any specific application in mind so it can be easily adapted to different experiments. Unfortunately, this technique is only capable of measuring the movement frequency since no direct connection has been found between pixel luminosity changes and vibration amplitude. Even though, frequency determination with simple and cheap non-contact method can be applied in a lot of areas and problems such as structural engineering, industrial mechanics and modal analysis.

In [15], an interesting idea was outlined: the possibility to extend the method for simultaneous multipoint calculation. This feature is of great interest since it would permit multiple measurements from a single experiment. Therefore, with a simple excitation, one could measure and compare the vibration frequency between different parts of an object, or even different objects, and obtain valuable information about the system dynamics.

Multipoint measurements have been implemented in Laser Vibrometers through a scanning mechanism but it may result very expensive, slow and measurements are taken asynchronically so, strictly speaking it is not a multiple point device. Other authors have proposed the use of radar interferometry in order to measure vibrations in structures and buildings [16–18]. The method is fast and accurate but it is still expensive and requires of special properties of the vibrating object in order to produce a clean signal. In [19], the authors propose the use of a Kinect sensor to obtain the time variation of vibrating three-dimensional surfaces. The system permits simultaneous measurement of multiple points in real time with a cheap device, but it is limited by the hardware to frequencies below 15 Hz.

In this paper, we propose a simple and low cost method for simultaneously measuring the vibration frequencies in all the points of a captured video sequence. The idea is developed from the algorithms presented in [15], which consisted of selecting a local neighborhood or region of interest (ROI) and applying a multilevel binary threshold to the image within this region. By proper combination and analysis of all binary levels the authors are able to obtain the vibration frequency of the part of the object within the ROI. Here, we exploit the idea and propose to extend the method and to analyze the frequency information in the entire scene and through the whole sequence. Therefore, the frame is subdivided in overlapping ROIs that are individually analyzed. Each ROI contains all the voxels through the sequence and thus allows the calculation of the vibration frequencies of each local neighborhood. With this information, a frequency map of the sequence can be built and represented. As we will see in the examples provided, this allows identifying different vibrating parts of a complex object and even recognize the source of the detected frequencies. Finally, we will implement a Short-Time Fourier transform algorithm so that we can obtain the frequency changes and variations occurring in a single sequence.

Compared with [19], our proposal is restricted to 2-D movements but it can be easily implemented with any camera. In fact, it has been used both with a high-end and a pocket camera with satisfactory results in both cases. Because of this versatility, the method is mainly limited by the camera configuration. In the following pages, we will show the capabilities of our proposal. The reader will notice that although the same example can be used for all the experiments, we decided to present different vibrating objects so that the performance and capabilities of the method is better understood.

The structure of the paper is organized as follows. In Section 2, we will recall the basic principles and algorithms that allow the calculation of the vibration frequency in a ROI from a high-speed video sequence. In Section 3, we will show the capabilities of the method for detecting and resolving frequency changes in the object within the ROI. In Section 4, we will extend the method to the whole frame to obtain a frequency map identifying different parts of an object vibrating simultaneously at different frequencies. Combination of the mapping option with the short-time Fourier transform will allow us to build a time-varying frequency video map, that is capable of detecting different objects vibrating both simultaneously or at different times. Finally, in the last Section, we will outline the main conclusions.

2. Method

In [20], the authors presented a discussion about the theoretical limits of object tracking with sub-pixel resolution.