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Uncertainty analysis of high frequency image-based vibration measurements

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ABSTRACT

Image-based vibration measurement techniques allow to remotely measuring the displacement of multiple targets in the field of view, without the need to mount anything on the measurand. In this paper the uncertainty budget of vision systems has been performed in order to both optimize the measurement procedure and identify the potential application fields. Two different types of camera are used in this work, both of them equipped with a 1280×1024 px sensor but with two different maximum frame rates at full resolution: 25fps and 2000fps respectively. The uncertainty analysis proposed here is based on a careful identification of the uncertainty sources and on experimental tests on an electro-magnetic shaker, where the displacement measured with the cameras are calibrated by means of the reference measurements provided by state-of-the-art traditional techniques.

1. Introduction

Nowadays there is a strong interest towards vibration measurement techniques based on image acquisition and processing because of their contact-less characteristics and the possibility to remotely measure the displacement of multiple targets in the field of view, without the need to mount anything on the measurand. These advantages make the vision-based vibration techniques particularly interesting in monitoring applications where the traditional approaches show a significant limit: the need to mount transducers on the structure to be measured. Just to make examples with relevance for safety and health, vibration monitoring of bridges, in case of low frequency ranges, and hand transmitted vibration studies, if frequencies in the order of a few hundred of hertz are of interest.

1.1. Image-based measurement of vibration

In literature the image-based measuring systems are usually considered particularly interesting for the measurement of low-frequency vibration because of two reasons: first of all the high frequency displacements are often characterized by amplitudes lower that the low-frequency ones and therefore as the frequency of the motion increases there is an increasing risk of getting insufficient resolution. Secondly it should be considered that the maximum acquisition frequency of most of the cameras in full resolution is no larger than 100 Hz, therefore the maximum vibration frequency that can be measured without aliasing is often limited to a few tenth of hertz. In recent years much faster camera were however developed, capable to acquire images with sampling frequencies up to a few thousands of hertz, allowing to capture and measure very fast displacement phenomena, such as transients or high frequency vibrations. The problem of the reduced amplitudes in the case of increasing frequencies is still an issue, therefore in this work an uncertainty analysis is done also in the case of high frequency image acquisition for vibration measurements.

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Nomenclature

σ_{ref}	uncertainty of the reference transducer
σ_{dyn}	mean standard deviations of the differences between patterns and reference
σ_{target}	standard deviations of the differences between target
σ_{lin}	standard deviations of the conversion factor C in the field of view of the camera
C	pixels to millimeters conversion ratio
Res_{px}	resolution provided by the method of image analysis (pattern matching), in pixels
σ_{res}	uncertainty of the resolution
σ_{tot}	total uncertainty

The level of cost and the complexity of any new measurement system can be either the main restraints or the reasons for success of the technique itself. On the other side the performances of any new approach must be known and granted, accounting for facts like resolution, sensitivity, and uncertainty. In this scenario, in order to verify the field of application of a vibration measuring methodology based on a vision system, two approaches have been considered in this work being based on different digital cameras (with strongly different maximum image acquisition rates) and on different methods of data acquisition and processing.

1.2. State of the art

Thanks to the development of the digital cameras, the increasing of the processing capabilities of computers and of the image processing libraries, in the last years the use of digital cameras to measure the vibration of targets is becoming popular, with particular reference to the vibration monitoring of civil structures [1–3].

One of the issues in this type of measurement is the type of feature used for the measurement: in most of the cases planar black and white targets are attached to the structure in order to improve the reliability of the measuring technique and to reduce the uncertainty of the results [2–4], while in other circumstances the natural texture of the structure can be used for the measurement ([3]). The main advantages of the marker less case are that the preparation of the set-up is much faster and that it is not necessary to have access to the structure to be monitored.

In [2] the vibration of bridges is done using fit-to-the-purpose target attached to the structure; in this case the target is constituted by one black circle in white background, while in [5] a planar target with four circles is used. In [6] cross-shaped targets are used and the viewing system is equipped with an additional reference system, which decreases the sensitivity to vibrations. Two types of targets are used in [7]: ring-shaped and random ones; in this case multiple target are measured contemporarily with a unique camera, allowing multi-point measurements. In some applications active targets are used; for example in [4] LEDs are used for suspended bridge vibration monitoring. Marker less solutions are proposed in [3], to monitor cable vibrations in cable-stayed bridges and of power-delivery lines respectively. In [8] and [9] the vibration measurements obtained through image acquisition and processing are used for structural damage assessment and structural health monitoring (SHM) respectively.

As for high speed vision systems, applications are found in literature, mostly used for robot control [10,11]: actions that are described for performance and accuracy improvement are specific and it is difficult to achieve information about system uncertainty to be used in general applications.

In the most of vision-based methods the vibration amplitude is measured analyzing a sequence of not blurred images recorded by high-speed video, however in the specific case of sinusoidal vibration it is possible to estimate the motion relying on motion blurred images, as proposed in [12].

In this work we will concentrate our attention to the performances of vision-based vibration measurements, considering the effect of some peculiar parameters, such as: the type of target, the vibration parameters (frequency and amplitude) and the acquisition condition (exposure time and image acquisition frequency).

2. Experimental set-up

Two different types of camera are used in this work: the first one, an AVT Marlin F-131b, reaches a velocity of 25 fps at full resolution (1280 × 1024 px), the second one is a high speed camera, Olympus i-speed, with a CMOS 1280 × 1024 px sensor, allowing to acquire up to 2000 fps at full resolution. In both the cases the dynamic calibration of the whole measuring chain based on the vision systems has been carried out by means of traditional vibration measuring instrumentation like non-contact laser displacement transducers and piezoelectric accelerometers.

Obviously, if the frequency range of interest for the tests is taken into account (almost 0–100 Hz for slow camera), the slow camera undergoes the aliasing phenomenon in a large part of the calibration frequency field. If

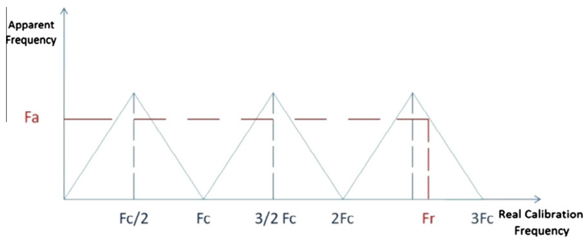

Fig. 1. Scheme real frequency-apparent frequency.