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Indexes for performance evaluation of cameras applied to dynamic measurements

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ABSTRACT

Thanks to technology improvements, the applications of vision-based measurement to dynamic applications have been increasing in the last years. The available image resolutions and the high grabbing frequencies allow to acquire high-speed moving object with a good scaling factor and to perform dynamic analysis of vibrating items. Uncertainty analysis of vision-based measuring devices working in almost-static conditions was widely studied in literature, but the case of dynamic measurements still needs a further analysis. The measuring performances thus depend on the well-known parameters that affect the static performances (image resolution and contrast, processing algorithm, noise, etc.) but also on other factors, above all the exposure time and the camera-object relative motion, in terms of instantaneous velocity and acceleration. In this work, a performance analysis of imaging devices applied to dynamic measurements is proposed. The analysis aims to qualify the measurement uncertainty by some indexes, proposed in this work, and designed to quantify the motion effect on the acquired images and consequently the measurement uncertainty. These indexes are based on exposure time and Spatial Frequency Response (SFR) function, which is widely applied in literature and recommended in international standards for the image quality estimation in static acquiring conditions. Appropriate developments of SFR are proposed herein to obtain information on the image quality grabbed in dynamic conditions. The effectiveness of the proposed indexes are proved by several tests, where a target is moved with an harmonic law in controlled condition (varying its frequency and amplitude) and fixing different acquisition conditions in terms of lighting settings, diaphragm aperture, exposure time, etc.

1. Introduction

Imaging devices have been intensively studied as displacement transducers in the last 20 years. There are many advantages in using such devices. First, the measurement is remote, contactless and dense, which means that it is possible to perform a multipoint measurement with one single camera, where each pixel of the sensor matrix is like a single transducer. Secondly, the measurement set up is really easy and flexible to manage, since only one camera, some targets and a personal computer are needed [1–3].

The use of imaging devices as displacement transducers was firstly proposed in almost-static applications, where the acquired object moves slowly with respect the acquisition parameters of the camera and therefore the target displacement during the exposure time can be neglected. Thanks to technology improvements, the applications of vision-based measurement to dynamic applications have been increasing in the last 10 years [4–7]. The available image resolutions and the high grabbing frequencies allow

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to acquire high-speed moving object with a good scaling factor and to perform dynamic analysis of vibrating items. Currently, a basic imaging device can easily acquires 1 Megapixel images with a 25 fps grabbing frequency, which means that it is possible to perform a dynamic analysis up to 12.5 Hz at full resolution, but there are also top level cameras able to acquire 2–3 Megapixel images with more than 2 kHz grabbing frequency. One of the most common application of vision-based techniques to dynamic analysis is the structural health monitoring (SHM), where vision-based measurements are used to identify displacements and vibrations of whole civil structures and their components [8–12].

Since imaging devices are used as transducers, some assessments about their measurement uncertainty should be done. Uncertainty of vision-based measurement is affected by several factors which define the image quality, such as image resolution, scaling factor (px/mm ratio or vice versa), focusing quality, lighting conditions, and image contrast, aberration. Their effects on measurement uncertainty are not easily quantifiable. For example, Cantatore et al. [13] and Shimizu and Okutomi [14] demonstrated that a moderate blurring may reduce the measurement uncertainty. Moreover, these image properties might be obtained adjusting several camera acquisition parameters, which could depend on each other. For example, different combinations of exposure time and diaphragm aperture could produce the same image luminance or contrast. However, this might be achieved with different side effects: reducing the diaphragm aperture decreases the image luminance, but it increases the depth of view; on the other hand, reducing the exposure time may obtain the same results on the image luminance, together with a decreasing of the amount of noise.

Since the quantification of the measurement uncertainty depends on several parameters, it is comprehensible how could be useful the definition of some synthetic indexes, in order to define the image quality and consequently the measurement uncertainty in static and dynamic conditions. The quantification of the measurement uncertainty when imaging devices are used in dynamic conditions becomes more challenging and important, since in this case other factors, in addition to those listed before, are fundamental to define the measurement performance, such as the camera-object relative motion in terms of instantaneous velocity and acceleration. The good displacement estimation will indeed depend on the dynamic camera parameters, such as grabbing frequency, but, most of all, the exposure time that must be settled to a proper value in order to avoid motion blurring.

In this work some indexes, based on exposure time and Spatial Frequency Response function (SFR), will be proposed and qualified. The indexes proposed in this work are suitable to define the measurement uncertainty both in static and dynamic condition and it will be showed how their behavior is linked to the measurement uncertainty. The results proving this statement are obtained by several tests, where a target is moved with a harmonic law in controlled conditions (varying its frequency and amplitude) and fixing different acquisition characteristics in terms of lighting conditions, diaphragm aperture, exposure time, etc.

In the next section, some concepts about the estimation of the image quality by means of the Spatial Frequency Response (SFR) will be fixed. The results performed in static conditions are the basic point to start the analysis in dynamic conditions. Then, in Section 3 the dynamic qualification are provided and in Sections 3.4-3.6 three indexes for the image quality estimation in the case of dynamic acquisition conditions will be proposed and applied. The advantages and the limits of these indexes will be shown and it will be proven how they can be applied to uncertainty measurement qualification.

2. Static qualification

The performance of cameras applied to dynamic measurement depends on several parameters; some of them can be evaluated in static condition, such as focus, lighting conditions, lens distortions, and image contrast. All these parameters work together to define the image quality. For these reasons, before performing an analysis focused on the dynamic performance, this section deals with some considerations about the imaging device behavior for acquisition in static condition. Some results about the image quality estimation will be presented with attention to image focus and diaphragm opening, which are parameters strictly linked to static acquisition, but also testing the influence of the shutter time value, which is linked both to static and dynamic acquisition. Shutter value, indeed, defines the amount of light impacting on the sensor but, most of all, the grabbing velocity of the acquired frames of the moving object. In this way, it will be possible to divide the contribution of static parameters from those of the dynamic parameters in the image quality definition, under dynamic grabbing condition.

2.1. SFR function

In static condition the image quality rendered by an imaging system can be evaluated by the Spatial Frequency Response (SFR), defined in ISO 12233 [15]. The SFR has been widely used to characterize the spatial frequency response of many kinds of imaging systems. It is defined as the modulus of the Optical Transfer Function (OTF), which is the Fourier Transform of the impulse response of the system [16]. It defines the ability of an optical system to resolve a contrast at a given resolution (or spatial frequency). Traditional methods for SFR measurements were initially designed for analog cameras [17–19].

However, when digital cameras are considered, these techniques can give misleading SFR results, because the sampling of digital devices is not properly considered. Additionally, SFR results estimated with the mentioned traditional methods can depend on the chosen technique (sine target or bar target utilization, slit or knife-edge technique). The ISO 12233 methodology has been established in order to provide a fast SFR measurement method based on one image only. In such a standardized way, the SFR