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MEASUREMENTS OF DISPLACEMENT OF THE STRUCTURE OF A REDUCED SCALE BUILDING LAB USING DIGITAL CAMERA IMAGES

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Abstract. *This paper presents a noncontact technique for displacement measurement based on the variation of the pixels positions of a target object in the images captured by CCD or CMOS sensor. The distance from the camera to the target object is defined by moving the camera along of its optical axis in backward (forward) directions and counting the variation of the number of pixels of the object from an image to other. Once defined the distance, the captured video is analyzed frame by frame and the variation of the pixels position of the target object is calculated for each frame and related with the position of the object in the image by using trigonometric relationship. To highlight the target points in the scene, the image frames are analyzed and processed with the aid of mathematical image processing tolls like threshold, erosion and dilation. The proposed approach is evaluated to measuring vibrations of a reduced scale building lab structure. The results obtained through the digital images analysis are compared with some measuring references of some point of the structure and have shown good agreement with makes the proposed a very promising technique.*

Keywords: *noncontact, measurement, digital cameras, vibration analysis*

1. INTRODUCTION

Many tasks performed by humans are mainly based on the sense of sight, through the vision man is able to identify, classify and understand the things that surround him. The visual interpretation of the world is natural to human beings; however its computational representation is difficult. The technology currently available has contributed significantly for increasing the capability of a scene interpretation through computational tools. They are used to the interpretation and recognition of different scene (pictures) for support decision-making or even for the replacement of the human being in some task.

In engineering, the measured displacement is common in all areas and there is a variety of techniques of measurements, using capacitive sensors, inductive sensors, laser, ultrasound and others. The techniques can be a contact or non-contact technique, but in most cases that is desired to measure simultaneously the displacement of a set of points or a region there is great difficulty for the measurement. This occurs because most sensors do not measure multiple points and the number of available sensors is often limited. The use of CCD or CMOS sensors as a measuring movement sensor appears as great option since they use allows one to obtain a picture of the whole scene of the interest and allows to the movement of a point or a set of points that can be captured simultaneously.

The methods of measurement of displacement with digital cameras as discussed in Egami et al. (2001), usually requires two cameras positioned at different angles to capture two different images for later analysis. Analysis is generally done frame-by-frame using correlation analysis techniques and pattern recognition to extract the characteristics and parameters of interest at the measured image. Thus, a huge storage capacity and processing speed is demanded in the application of these systems (Hsu et al., 2009) for dynamic measuring.

An alternative approach to the use of two cameras is discussed in Hsu et al. (2009), in which the authors use only one digital camera to measure the distance between the camera and one object. The distance of the object is obtained by counting the number of pixels of a reference line in the image. In this case, the camera is positioned perpendicular to the target so that it can move (known value) in line with the optical axis toward (forward) to the object and the variation of the number of pixels between the reference line in the captured image obtained approaching the camera to the object and the reference image is used to determine the distance.

This paper discusses a proposal of displacement measurement using a digital camera, the implemented approach is based on the method proposed by Hsu et al (2009). In this case, the displacement measurement of a point or set of points of a target objet is obtained through an analysis, frame by frame, of the captured video. Each frame of the video is analyzed and the positions of the target object is defined in terms of pixels and compared with a fixed reference. The variation of the pixels position of the points is observed and its motion is calculated.

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2. MEASURING DISPLACEMENT BASED ON VARIATION OF THE TARGET OBJECT.

2.1 Relationship between target size and the pixel

The distance measurement system based on the variation of the pixels position of a target object in the images captured by the digital camera is developed from the triangular relations between the camera and object. In this case, assuming that the object is perpendicular to the optical axis of the camera, there is a direct relationship between the object size and distance of the camera. This distance can be obtained counting the variation of the number of pixels of the object from one image to other, when the camera moves toward/forward to the target object. Figure 1 shows a schematic diagram of a CCD camera to capture images of an object for two different shooting distances, h_1 and h_2.

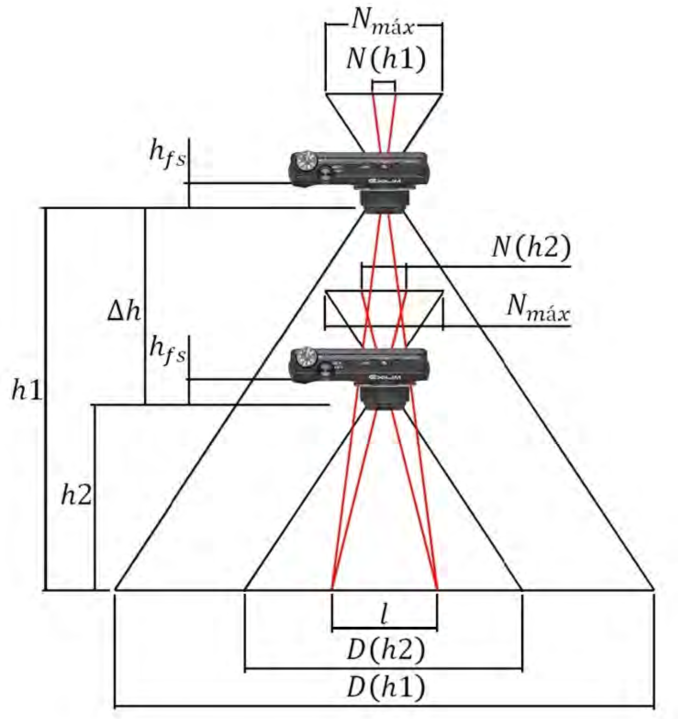

Figure 1. Schematic diagram of camera positioning.

Assuming that the object is perpendicular to the optical axis of the camera, there is a direct relationship between the size of the object, ℓ, and for two different shooting distances, h_1 and h_2 displacement of the camera (Δh). Consequently, there will be a variation of the number of the pixels of the target object from the shooting distances h_1 and h_2. So, due to the provision of the given target/object of size ℓ, the number of pixel to represent the object with the camera in position h_1, termed $N(h_1)$ is a function of the distance h_1 and the number of pixels to represent the object in position h_2, termed $N(h_2)$ is a function h_2. Based on these information, one will find the estimated values of the distances h_1 and h_2, Eqs (1) and (2), function of the number of pixels and the optical distance (h_s).

$$h_1 = \frac{N(h_2)}{N(h_2)+N(h_1)}\Delta h - h_s \qquad (1)$$

$$h_2 = \frac{N(h_1)}{N(h_2)+N(h_1)}\Delta h - h_s \qquad (2)$$

Once determined the distance from the camera to the object, Sabino et al, (2012), it is possible to estimate the actual size of the object, and thus establish a relationship between the length of the object and the number of pixels, Eq (3).

$$\Delta d = \frac{D(h_1)}{N_{\max}}\left[{}^{unit}\!/_{pixel}\right] \qquad (3)$$

Where $D(h_1)$ is the estimated length of the image given in the unit of measure and N_{max} is the maximum number of pixels of a row or column of the image.

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2.2 Image processing

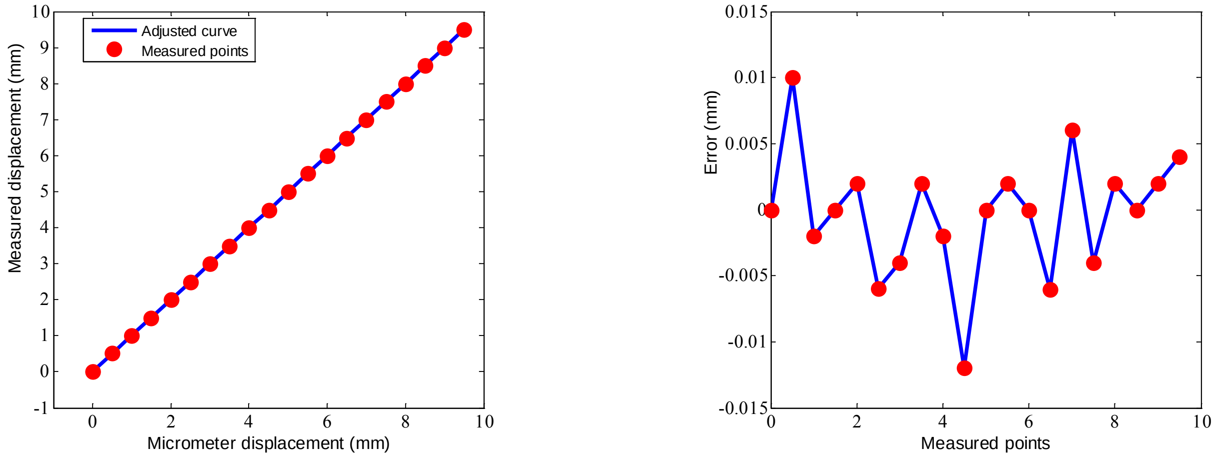
In the proposed approach the displacement of the target object is obtained in 3 steps. In the first step the recorded video is read (frame-by-frame), in the second step the images are processed using some specific image processing tools aiming at highlight the object in order to distinguish it from the rest of the scene and in the third step the position of the target object in the image (scene) is identified in term of pixels.

The processing stage is initiated selecting the video and defining the morphological structure of the object to be found in the images. The RGB images are converted to the binary format and conventional image processing tools are used, more specifically, threshold, and limits edges (Gonzales and Woods, 2002; Castleman, 1996) to separate the target object from the rest of the scene. Once identified the target object, the algorithm calculates the position of its centroid in terms of x and y coordinates position, given in pixels, and the changing of the position from a frame to other is used to calculate the displacement of the object (item 2.1). In the capturing stage of the video it is interesting that the target object presents some contrast to the rest of the scene. It would facilitate to separate and obtaining more precise positioning of the target object in the scene.

3. EXPERIMENTAL TEST FOR VALIDATION PROPOSE

Initially to evaluate the capability of the proposed methodology, it was use to measure a set of reference values (standard dimensions) defined by a micrometer of precision. The experimental apparatus for this test consisted of a digital camera model Logitech STX with maximum resolution of 640 × 480 pixels, capture rate of 30 frames per second (fps) and a vision field of 42° coupled to a computer, the micrometer (precision of 0,002 mm) and some devices (mounting base) to fixe and positioning the equipments. The experimental Set-up was mounted in an inertial table and the displacement of the rod of the micrometer (target object) was measured by using the camera and the result were compared to the values provided by the micrometer. The road of the micrometer had a displacement of 9,5 mm, from increment of 0,5 mm to 0,5 mm, and at each applied increment (standard value), the displacement of the road was measure by using the camera.

In the Fig. 2a it is shown a plot of the standard values (micrometer reading) versus the measured values (using the camera) and in the Fig. 2b it is given the estimated error for each measuring increment. The largest difference was 0,012 mm, it also is possible to observe that the errors do not present tendency, it is almost equal spread to the whole measuring range.



(a) (b)

Figure 2. Comparison of the measured and reference data - (a) reference displacement versus measured one (b) error of the measured data.

The analysis of the result data shows that the largest error in the measured data is the order of 2%, which is equivalent to those error observed in the literature or obtained with traditional methods using two cameras (Hsu et al., 2009).

4. STRUCTURAL VIBRATION OF A REDUCED SCALE MODEL OF A TWO-FLOOR BUILDING

The methodology was validated in the previous section and now it will be used to measure the vibration of a two-floor Building scale reduced structure. The structure (Fig. 3) is manufactured by Quanser Consulting Inc, with two

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floors. It has 1125 mm in height, with each column being steel with a section of 1.75 × 108 mm. The total mass of the structure is 4.52 kg, where the first floor mass is 1.16 kg, the second floor mass is 1.38 kg. One universal power module is used as power amplifier; it is used to power the shaking table. The data acquisition and control board used to collect data and drive the power amplifier is a MultiQ-PCI.

The control system of the building consists essentially of a controller guided by Simulink, formed by the sensor/actuator and the corresponding conditioners. This system permit to simulate different conditions of vibration of the building, the excitation signal is sent to the actuator (motor) positioned at bottom of the building structure that replicate the signal generated by the controller, leading the building to vibrate according to the excitation. The motor controller is based on displacement and a proportional-derivative (PD) controller is used for shake-table position control using the reference position signal.

Figure 3. Reduce Scale Model of Two-floor building.

Two tests were conducted and the methodology was used initially to measure the vibration of the structure due to a sinusoidal excitation and later it was used to measure de vibration of the structure caused for an real earthquake scaled signal.

4.1 Experimental apparatus

The experimental setup was assemble on an inertial table and measuring system consisted of a digital camera placed in front of the building, perpendicular to it, fixed to a tripod and one spotlight was fixed behind to the camera aiming at improving the environment lighting for the video recording.

The displacement of the structure was measured simultaneously on 25 different points. Each measuring point received an adhesive label aiming at facilitating their definition in the whole image during the image processing step. Each column received 12 labels on the back part and 12 labels on the front part, and finally, an additional label was fixed on the base of structure exactly in the point where the actuator (motor) excite the structure. Figure (4) shows a view of the experimental setup used.

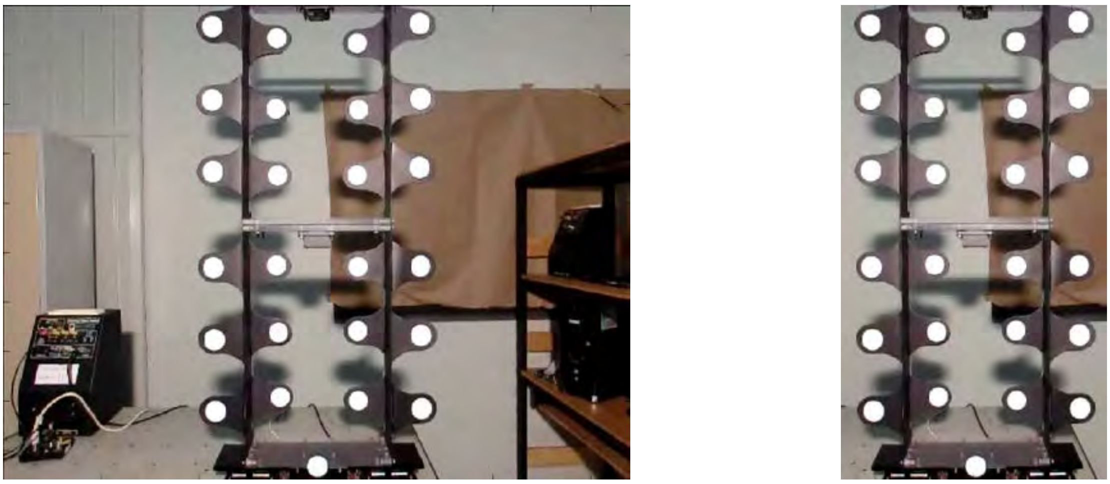
Figure 4. System for measuring vibration of a two-floor building.

The camera was positioned correctly and adjusted to capture the whole structure and the image acquisition rate used was 120 fps for a resolution of 640x480. Initially, before to start the recording of the movement of the structure the system was calibrated, that means, the distance of the camera to the object was determined (section 2.1) in function of the parameters of the camera.

Two distinct tests were conducted. For the first test the structure was excited with a sinusoidal signal and for the second one the structure was excited with a real earthquake scaled signal. In the first case the camera was triggered to initiate the recording processing after the transient component have gone away and in the second one it was triggered to initiate the recording before the structure was excited.

4.2 Image processing of Structure

The image processing step allowed obtaining the position of the target points in the image for each frame and corresponding pixels number. The image was cropped at the region of interest in order to eliminate the undesired points or components that can appear in the scene that are not of interest. This decrease the processing time and facilitate the identification of the target points in the image. Figure 5a and 5b shows respectively the image of the whole scene and the cropped one. After defined the region of interest the threshold, erosion and dilation tools (Gonzales and Woods, 2002) were used to separate the target objects from the rest of the scene and the position of the centroid of each target point for each frame was calculated. The changing of its position from the reference frame was calculated in terms of pixels to be used to calculate the corresponding displacement of each target points (adhesive labels).



(a) (b)

Figure 5. Original image - (a) and cropped image in the region of interest (b).

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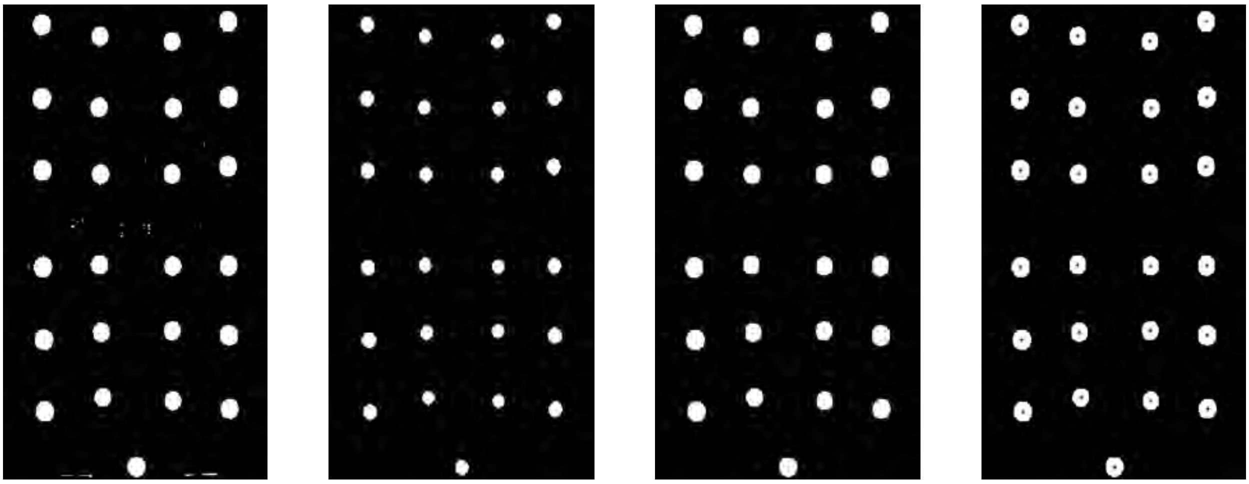
In the figure 6 it shown some step of the image processing stage to identify and separate the target point from the rest of the scene according to the employed tools.



(a) (b) (c) (d)

Figure 6. Threshold - (a), Erosion – (b), Dilation – (c) and Calculating the centroids - (d).

Once defined the position of each target point and knowing the value of the correction factor Δd (section 2.1) it is possible to obtain the displacements of the targets in the corresponding measuring unit.

4.3 Measuring displacement of the structure for a sinusoidal excitation

The propose of this test is to evaluate the capability of the methodology not only for static measurement as discussed in the chapter 3 but also for dynamic application. In this case, it was used a very simple known signal for the excitation of the structure.

The structure was excited by base, in displacement, and the response was measured at the point where the actuator (motor) excite the structure. This point was chosen in order to compare the measured signal with the reference signal applied to the base of the building. The applied signal was a sine wave of 3 Hz that drives the actuator to impose the corresponding displacement to the base of the building. The motor controller is based on displacement and a proportional-derivative (PD) controller is used for shake-table position control, using the reference position signal.

In the Fig. 7 it is shown the superposition of the reference signal sent to the electric motor, the signal of the response of the motor, which was read by an encoder to control the structure and the corresponding signal measured by the camera, as well as, their respective spectrums. In the Tab. 1 it is shown the RMS values of each signal.

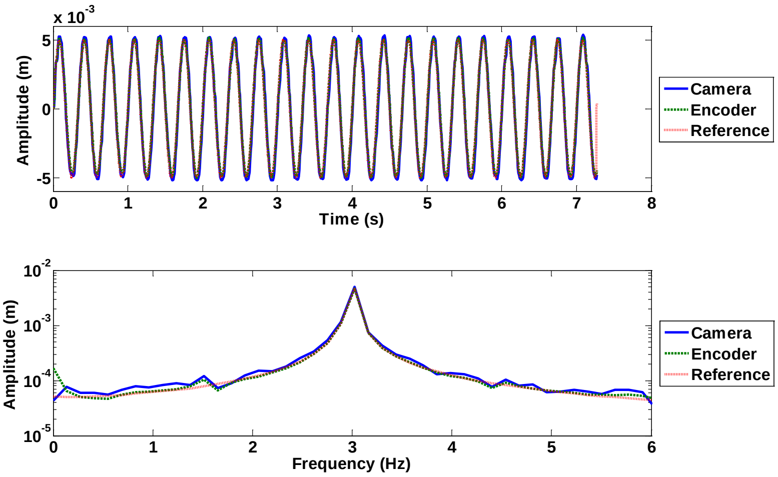


Figure 7. Comparison between reference signal and the measured signals and their spectrums.

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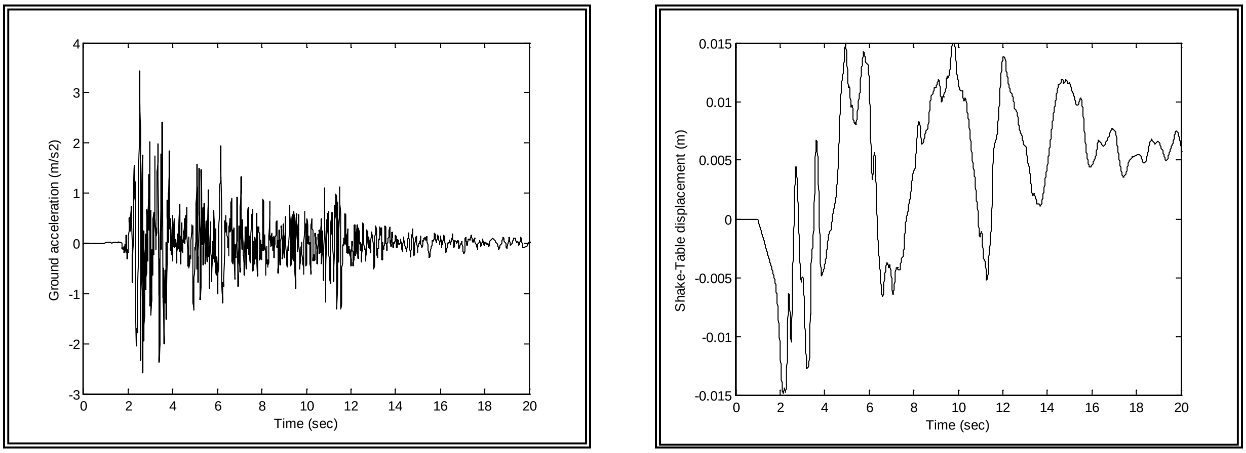
Table 1. RMS values to a sine wave

	RMS
Reference	0.0035
Encoder	0.0035
Camera	0.0036

The comparison of results values gives a difference of about 2.8% between the signal measured using the camera and the others. In these tests, the error was considered sufficiently small and this shows that the parameters discussed above (section 2.1) have been adequately estimated.

4.4 Measuring displacement of the reduced scale model of two-floor building

In this test the structure is analyzed for a more realistic condition of vibration. An earthquake-type excitation was inputted to the shake-table system as an excitation source. The building test-bed on the shaking table was excited by the El Centro earthquake scaled signal shown in Fig. 8a, occurred on 1940 in the Imperial Valley in southeastern Southern California (Filiatrault, A., 2002). Since the motor controller is based on displacement of the system, the acceleration signal shown in Fig. 8a was integrated twice to obtain displacement of the car excitation. A proportional-derivative (PD) controller is used for shake-table position control using the reference position shown in Fig. 8b (Abreu and Junior, 2010).



(a) (b)

Figure 8. El Centro earthquake ground acceleration used for seismic excitation - (a) and the Shake-Table position reference used by the PD controller – (b).

Initially the response of the structure was measured at a point close to the position of the actuator (motor). In the Fig. 9 it is shown the superposition of the reference signal (earthquake) sent to the electric motor, the signal of the response of the motor, which was read by an encoder to control the structure and the corresponding signal measured by the camera. In the Tab. 2 it is shown the RMS values of each signal.

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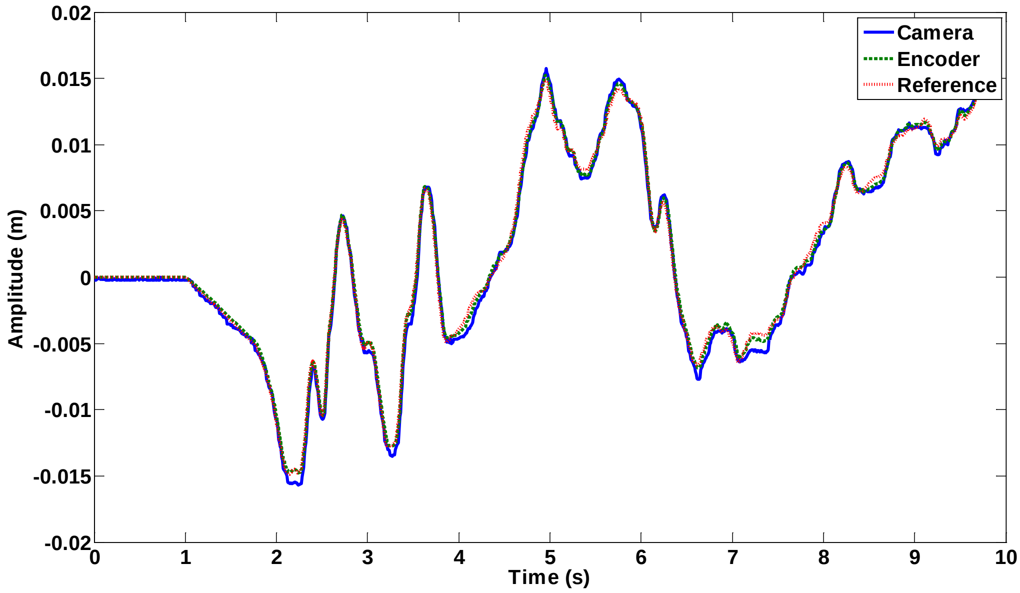
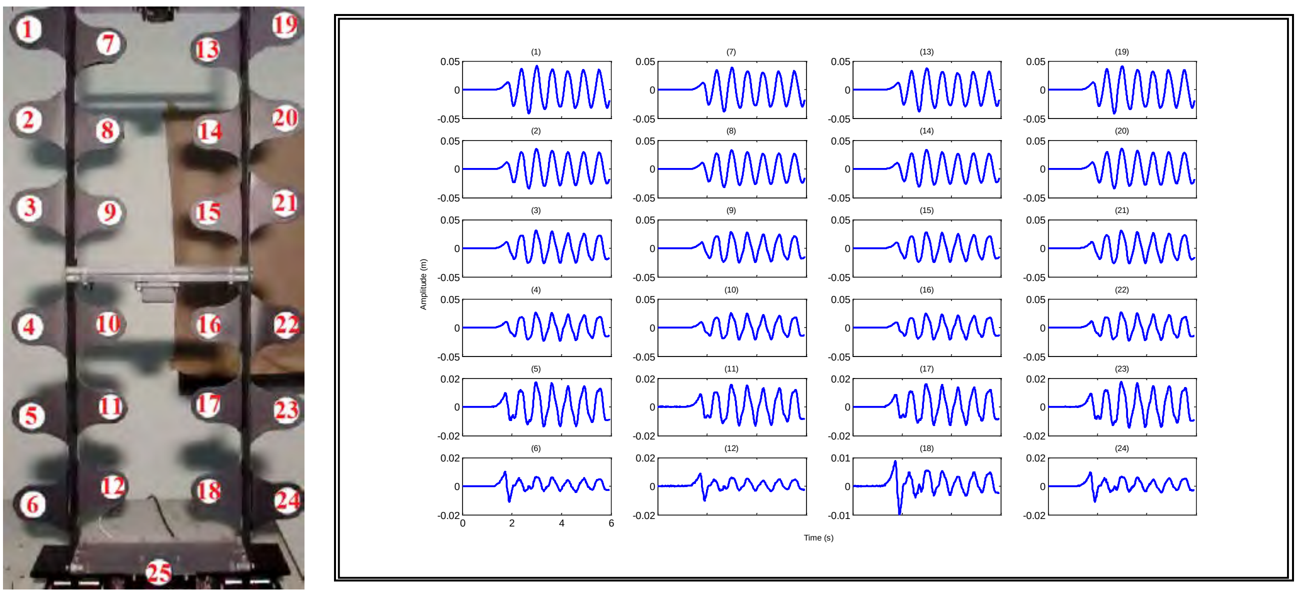


Figure 9. Comparison between signals in seismic excitation.

Table 2. RMS values

	RMS
Reference	0.0025
Encoder	0.0026
Camera	0.0027

The structure vibration also was measured for other points. In the Fig. 10a is presented the map of measuring point and in the Fig. 10b it is possible to see the measured displacement of each measured point of the building.



(a) (b)

Figure 10. Points named – (a) and all signals measured from building – (b)

The analysis of the obtained data demonstrated the applicability of the technique for static and dynamic measures, evidencing, its potential of application, for example, for tests and analysis of deformation (static loads), vibration and modal analysis of structure (dynamic), with a great possibility of application for operational modal analysis.

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5. CONCLUSIONS

The article discusses a proposal of displacement measurement using a d igital camera applied to measure the vibrations of a building reduced scale lab structure. Initially, the technique was evaluated by using a micrometer to validate the results and later it was applied to measure the vibrations of the building. The results of the measuring proposal compared with the micrometer showed a good agreement and the difference of the values were in the same order of the techniques using two cameras found in the literature. The comparison of the base movement of the building measured with the camera and with the encoder signal for the control of the building showed a good correlation. The methodology was also used to measure simultaneously the displacement of a set of discrete points of the vibrating structure which could be used for operational modal analysis of the structure. The proposed approach was used for different measuring conditions (static/dynamic) and results have shown great potential of application of the methodology as noncontact measuring tools, relatively simple and effective.

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