IMPLEMENTATION OF CAMCORDERS TO MEASURE DISPLACEMENTS IN STRUCTURES

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This study evaluates the use of high-definition camcorders for structural monitoring with the objective of developing a cost-effective, high-resolution, highly versatile system to measure dynamic displacements. The use of this system, allowed for the estimation of displacements at selected points of the structure using motion pictures taken during load solicitations. By applying target recognition algorithms in digital images to the motion pictures taken by means of high-definition camcorders, it was possible to determine the history of displacement corresponding to the load solicitations.

The performance of the system was evaluated through a set of laboratory tests in a shaking table. The displacements were captured simultaneously with a camcorder and a high-precision optical system, and their measurements compared.

The basic procedures for data acquisition and the complexities involved in the post-processing of video signals obtained during the shaking table tests are discussed in the paper. Different light conditions, changes in the distance to the target point, weather effects, among other variables were studied.

Furthermore, the implementation of the displacement identification algorithm is been evaluated to identify its advantages and limitations. This will be paramount in developing the criteria for optimal location of cameras and target points for measurement.

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ABSTRACT: In this study the use of high-definition camcorders for structural monitoring with the objective of developing a cost-effective, high-resolution, highly versatile system to measure dynamic displacements is evaluated. The system was calibrated through a series of tests in a shaking table comparing the estimated displacement with the data from displacement transducers and a high precision optical system, which allows evaluating the main advantages and limitations in the identification algorithm.

1 INTRODUCTION

Due to constant dynamic and static load solicitations during a structure lifetime, its properties tend to degrade. For such reason, their constant monitoring is an important activity, since it allows defining the required maintenance activities to prevail the structure in optimal conditions to accomplish its functions.

One of the most efficient ways to perform such monitoring is by instrumenting the structure with a set of sensors placed in strategic points allowing estimating its properties. In bridges, the identification of deflections and lateral displacements is a fundamental part of the property monitoring, however, in long span bridges or with high decks, the installation of traditional sensors to measure them could be complicated; for that reason, the need of equally precise but easier to implement alternative systems has arisen.

An alternative that accomplish with those needs, is the implementation of high-definition camcorders to estimate displacements at selected points of the structure. This technique is based on the identification of position changes during load solicitations from a set of digital images by applying target recognition algorithms (Olaszek, 1993 and 1999; Cooper and Robson, 1994; Stephen et al, 1993; Lee and Shinosuka, 2006; Caetano and Silva, 2007; Gamache and Santinni-Bell, 2009).

In this paper the algorithm implementation basis are described, and the results of a set of laboratory tests in a shaking table in order to evaluate the methodology is presented.

2 METHODOLOGY

This section describes the methodology used to identify position changes in image sequences for the estimation of displacement, and the principal criteria for selecting the proper equipment for that purpose.

2.1 Identification of change of position in images

A digital image is formed by a set of points, named pixels. The pixels are coded as a group of bits of fixed length, which represents the color intensity. Such intensity indicates the amount of colors in binary base for every pixel. For example, an 8 bits pixel contains 256 colors while a 32 bits one has over 16 million.

It is worth mention that the color and intensity of a pixel is composed by four main color channels: cyan, magenta, yellow and black (figure 1). The luminosity, however, is ruled by the black channel. Is important to notice that if the other colors are discarded, the luminosity and color intensity depends only by this channel, such images are known as grayscale images.

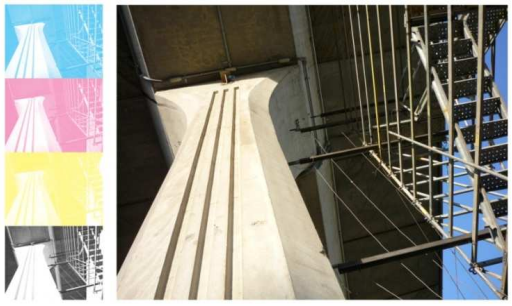
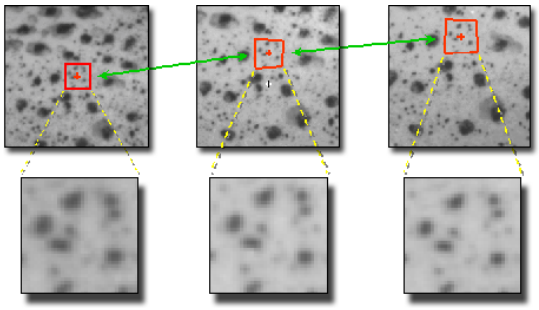


Figure 1. Color components of a digital image.

Another important property in digital images is their density, which is the number of pixels contained in a fixed area, this is known as resolution ratio and the units are pixel over square inch.

By knowing the pixel color intensity and the image resolution ratio it is possible to establish the pixel position in the image. Furthermore, by assuming that the pixel color intensity keeps approximately the same during a sequence of images and the position is calculated on each of them, is possible to estimate a trajectory pattern during the time line of the sequence.

However, due to the probability that light conditions changes or another external factor affects the color intensity during the image sequence, it is not recommended to obtain the trajectory from a single pixel, but from a group of nearby pixels. This permits to evaluate the existent correlation factor between the group in the reference and in the new position image for each picture (Allemang, 1982), a bigger correlation corresponds to a smaller estimation error and implies certainty in the identified position (figure 2).



a) b) c)

Figure 2. Group of pixels (a) and identification of its new position after a movement (b and c).

In order to evaluate the differences between every element of the reference group and the new position group, a least squares error function is defined in equation 1 (Schneiderman and Kanade, 2004).

$$E(x,y,u,v)=\sum_{i,j=-n/2}^{n/2}\left(F(x+i,y+j)-G(x+i+u,y+j+v)\right)^2 \qquad (1)$$

Where E is the estimation error; F is the group of pixels in the reference picture; G is the group of pixels in the new position image; x and y are the centroid coordinates of the reference group; u and v are the new position centroid coordinates of the group, and n is the size of the group.

It is important to notice that the identification time of the pixel intensity color will be reduced by using grayscale pictures since the possible combinations goes from 1.72E+08 (4 elements with 256 probable values) to just 256 colors (1 element with 256 probable values).

With the smallest error position found, the displacement can be calculated with a numeric subtraction (equation 2).

$$d_N = N_{IR} - N_i \qquad (2)$$

Where d_N is the displacement, N_{IR} is the centroid coordinate in n direction of the reference image and N_i is the centroid coordinate in n direction of the new position image.

With equations 1 and 2, it is possible to estimate the displacements in points of interest of a structure during in a sequence of images.

2.2 Criteria for selection of proper camcorders

According to consulted studies (Caetano and Silva, 2007; Gamache and Santinni-Bell, 2009; Lee, 2007; Olaszek, 1999) and the characteristics of the identification procedure, it was observed that proper selection of the capture equipment is essential to obtain a reliable and robust estimation, for this reason, a set of selection criteria was establish:

- **Resolution Capture:** The importance of this point lies in the ability to get as much information as possible in the capture, allowing the estimation of the displacements as accurately as possible. Given that the minimum resolution for HD devices will be up to 1 / 1920 while on a standard definition device it will be 1 / 720, both values are for reference only, since with the correlation procedure and interpolation techniques it is possible to reduce them (Caetano and Silva, 2007)
- **Distance to target**: This criterion is directly linked with resolution since in longer distances, the measure object will be reduced and the estimation accuracy will be reduced; however, it can be recovered with the camcorders zoom capacity.
- **Lighting linearity and glare response:** A sensor in the camcorder automatically corrects the exposure to light and keeps stable light levels that may occur during capture is necessary, because this minimizes the possibility of blind spots.
- **Sampling ratio:** The importance of this point lies in the type of event that will be captured, that is, if the movement is dynamic or quasi-static. The sampling ratio in medium profile camcorders can go up to 50 Hz.

3 SYSTEM EVALUATION

To evaluate the proposed displacement estimation system, a set of laboratory test in a shaking table at Instituto de Ingeniería of the Universidad Nacional Autónoma de México (II-UNAM) was made. A square HSS steel bar of 1 m long, 102 mm wide and a 9 mm thickness was fixed to the table with four screws in a welded base plate (figure 3). At the top of the bar a 102 mm metal plate was placed which was used as a target area for the capture with the camcorder.

For the test a high definition camcorder was selected using the criterion previously established. This device has an optical zoom lens with 15 augments, a light sensor responsive to sudden changes in 0.4 s and a sampling ratio capacity of 60 frames per second.

An optical measuring system of high accuracy (K600-DMM Kryton, Metris) and four displacement transducers was additionally used to compare results. The position of those instruments is shown in figure 4.

Given the large stiffness of the table in his plane it can be assumed as infinitely rigid, therefore, the movement of the steel bar can be determinate from the table corner displacements measured. It is also worth mentioning that, since the natural frequency of the steel bar (75 Hz) is higher than the vibration frequencies applied in the tests (up to 25 Hz), movements in the base and the top of the bar were approximately the same, as shown below.

The camcorder was positioned at 10 m from the area target; this implicates that without zoom it had a length of 25 pixels, which was incremented to 350 with the full zoom (figure 5).

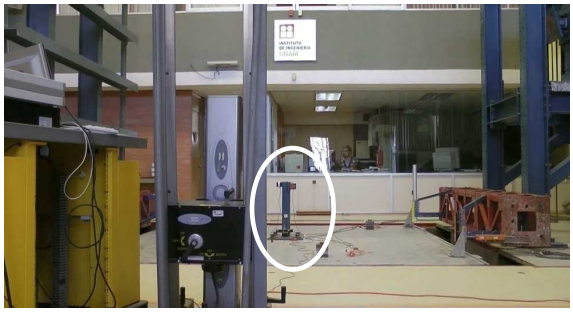


Figure 3. Shaking table at II-UNAM with the steel bar and the target area.

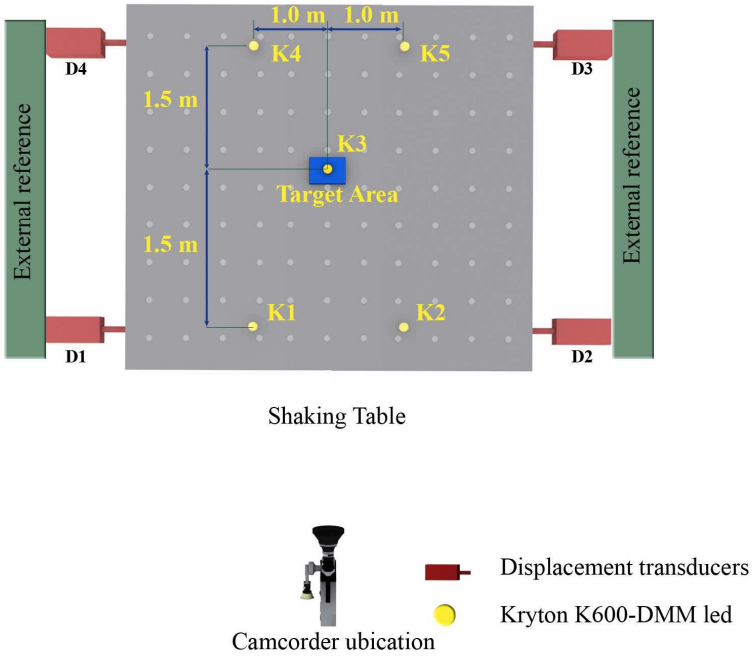


Figure 4. Instrument position during the shaking table tests.

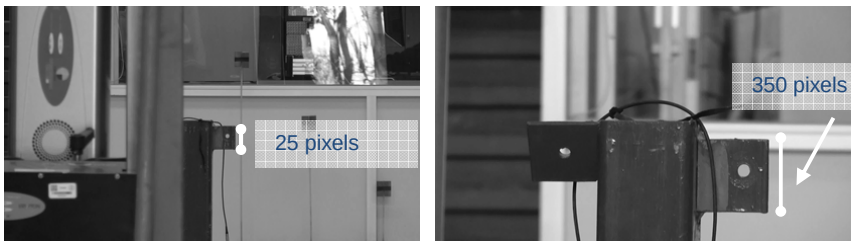


Figure 5. Target area and length with different zoom levels.

3.1 Evaluation Tests

The description of the tests is presented in table 1. Three tests were conducted with harmonic movements with natural frequencies from 0.1 to 1 Hz. To evaluate the accuracy of the method to quasi-static movements or very low frequencies, in tests 4 and 5 the movement consisted of a series of steps of vertical displacement of the table from the ground up to a fixed displacement, which was 25 mm for test 4, and 9 mm for test 5.

Furthermore, to assess the capacity to estimate displacements in dynamic events with the camcorders, in test 6 a Gaussian noise with a frequency band between 0.1 and 25 Hz, and displacements up to 20 mm was captured. In the capturing of data of tests 1 to 4 the optical zoom was not used, while for tests 5 and 6 the full zoom of the device (15 magnifications) was used.

The captured images in the tests were processed using a pattern recognition and localization routines in the computer program Matlab. To identify the displacements, a set of points were selected in the first picture taken as reference. Their position in the subsequent images was identified to estimate the displacements.

Table 1. Tests and employed movements for the evaluation.

Test	Movement
1	0.1 Hz harmonic, acceleration of 50 cm/s² with maximum displacement of 50 mm
2	0.5 Hz harmonic, acceleration of 50 cm/s² with maximum displacement of 50 mm
3	1.0 Hz harmonic, acceleration of 50 cm/s² with maximum displacement of 15 mm
4	Step movement from 0 to 25 mm with variations of 2 mm every 5 s
5	Step movement from 0 to 9 mm with variations of 1 mm every 5 s
6	Gaussian noise with frequency sweep from 0 to 25 Hz , maximum displacement of 20 mm

3.2 Tests Results

One of the uncertainties to verify was if the displacements measured on the basis of the table were the same as those at the top of the steel post. For that reason, the base leds and the transducers were compared with led K3 (figure 6) finding that all of them were similar.

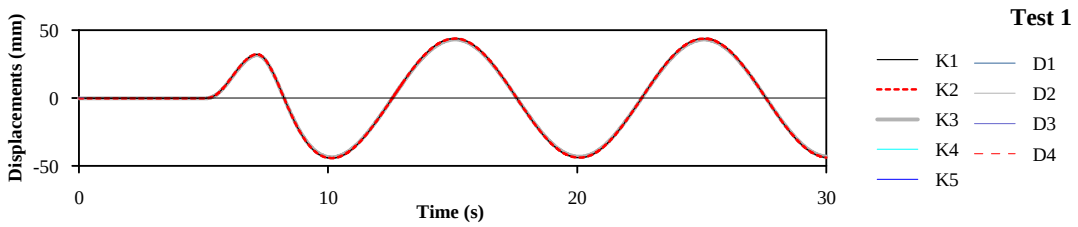


Figure 6. Comparisons between displacements measured with the transducers and the Kryton K600-DMM in the shaking table at test 1.

Displacements obtained with the Kryton K600-DMM and the transducers were compared with those estimated from the camcorder. The results of tests 1 to 3 and the comparison described above are shown in figure 8. In these tests there were a high accuracy between the camcorder and the other two systems.

The results for tests 4 and 5 are presented in figure 9. In test 4, there was a lack of resolution in the capture, although the movements match on several points, in others there are differences in magnitude and duration. This indicates that when the magnitude of the displacements is reduced, the resolution of the target area decreases and therefore the measurement accuracy is reduced too. This was confirmed in test 5 where with a higher zoom level, the accuracy increased to values similar to those obtained with the transducers and the system Kryton K600-DMM, so it was concluded that captures must be made using the highest possible zoom level.

Finally, the results obtained in test 6 are shown in figure 10. It can be seen that the displacements obtained with the video system, have high accuracy when compared with those obtained from the other two systems.

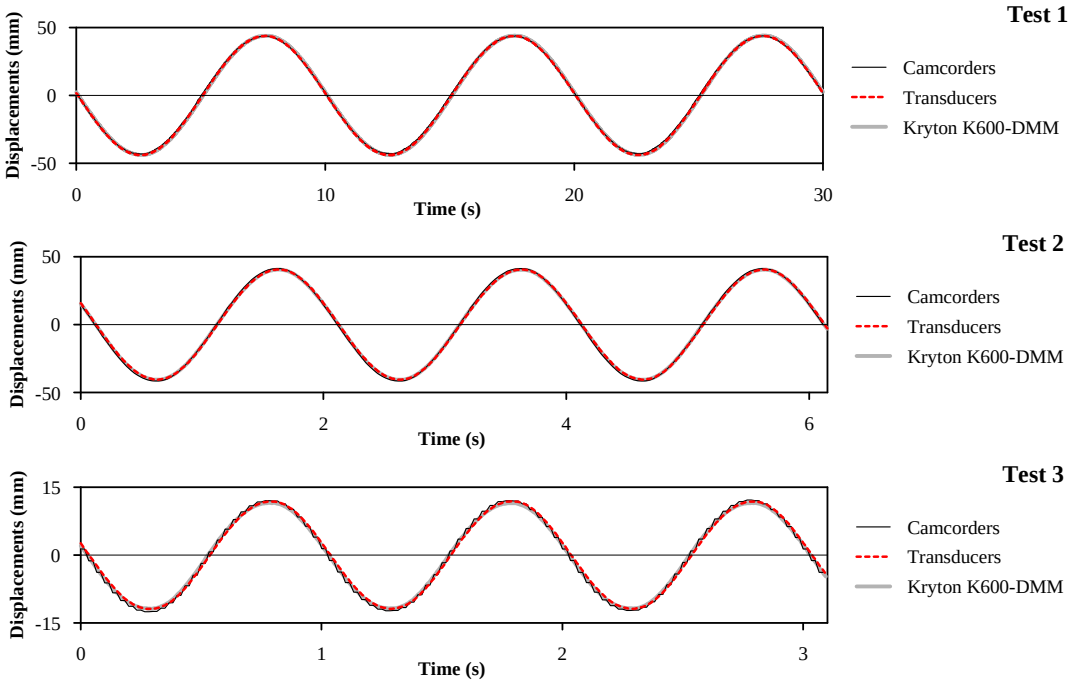


Figure 8. Displacement estimated in tests 1 to 3 with the camcorder, transducers and Kryton K600-DMM.

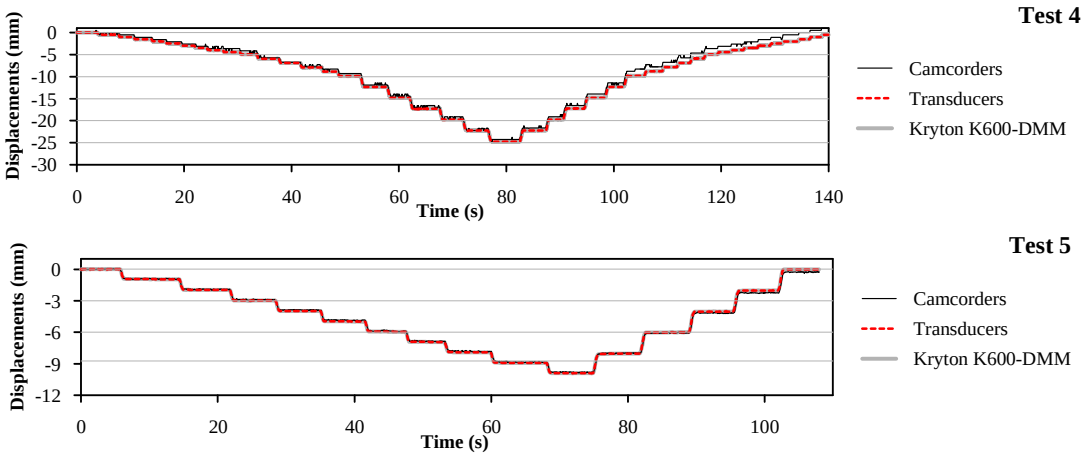


Figure 9. Displacement estimated in tests 4 to 5 with the camcorder, transducers and Kryton K600-DMM.

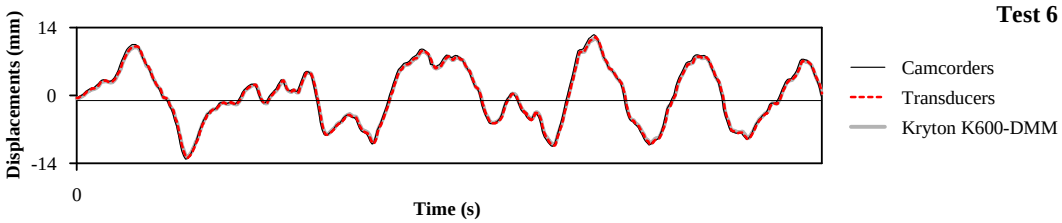


Figure 10. Displacement estimated in test 6 with the, camcorder, the transducers and Kryton K600-DMM

4 FINAL COMMENTS

An alternative for estimating displacements in structures from sequences of images taken by high-definition camcorders was presented, which is a good alternative, as the results obtained have a good level of accuracy and precision when compared with the data from other sensors.

To facilitate the identification of changes of position in image sequences, the instruments for the video capture must be placed in spots where they have full vision of the interest points of the structure, and if possible, such points must be marked using high-contrast textures.

Due to the good performance observed in tests with controlled movements, it is planned to implement the system in field tests on an elevated railway. The instrumentation will have a wide range of conventional sensors; including LVDT's that will make possible to compare the movements recorded and evaluate the performance of the displacement estimation using camcorders.

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