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BRIDGE DISPLACEMENT MEASUREMENT SYSTEM USING IMAGE PROCESSING

J.W.Lee
Structure Research Department, KICT, South Korea

J.W. Kwark
KICT, South Korea

E.S.Choi
KICT, South Korea

W.J.Chin
KICT, South Korea

J.W.Lee
DongYang University, Korea

Abstract

Large structures, like bridges and tall chimneys, suffer degradation with time, which sometimes may result in a big disaster – such as a breakdown or a collapse. These kind of accidents can be predicted by measuring and monitoring the history of the displacement or vibration of the structures. A solution is proposed through the development of a bridge displacement/vibration measurement system using image processing. This system, is composed of a computer with a digital camera, telescope lens, and a target mark that enables to overcome the drawbacks of contact type systems that are heavy, expensive and the need for a temporary support structure. The key idea is a self designed target mark where pixels to mm ratio can be calibrated by the program. The system is implemented and the experimental results are compared with a contact type system.

INTRODUCTION

Inspection and diagnosis of bridge structures are currently performed periodically for maintenance purpose. However, previous methods are mostly conducted by installing contact type sensors in the substructure of the bridge, which sometimes leads to tremendous difficulties according to the conditions of the substructure. In addition, the installation of temporary facilities for the fixation of the sensors as well as the attending equipments for storing and amplifying the signals, requires huge costs. In regards to such aspect, the equipment currently used for safety diagnosis purposes is far from being practicable. Therefore, the need for equipment enabling easy measurement of the dynamic displacement of bridge structures is tremendous. Accordingly, this study intends to develop a "non-contact" vibration measurement system using image processing. The technology developed in this study records the movements of a target stuck on the relevant structure using a camera, and automatically measures/stores the vibrations of the structure through an image processing technique. In order to realize a maximum portability and easiness of installation, a commercial camcorder has been selected as a measurement sensor and its original functions, shooting, storing and replaying, have been exploited at the most. Moreover, assuming the size of the target itself as the reference for the measurement of the displacement and acceleration of the bridge, automatic calibration has been implemented. The filmed results can be verified directly on site after image processing, and the signals recorded by the camcorder can be processed through replay.

COMPOSITION OF THE NON-CONTACT VIBRATION MEASUREMENT SYSTEM

Specifications

The target specifications of the system are as follows. Since the largest distance between the piers remains below 400m, the distance specification is setup to 200m. The sampling rate relies mainly on the camera specification, but is also limited by the algorithm, and computer processing power.

Table 1: Specifications of the system

Item	Specification	Remark
Type of vibration	Static and dynamic	
Distance	Up to 200m	
Resolution	Up to 50um	Standard target size
Sampling rate	Up to 100 FPS	

Hardware

The system consists of a processing computer, a camera with a telescope lens, and a simple target mark as illustrated in Figure 1.

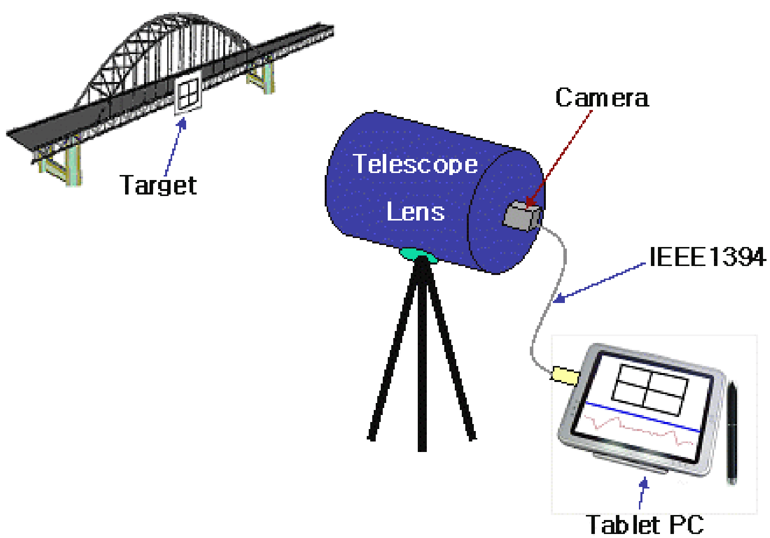

Figure 1. Hardware composition of the system

The target is a cross mark inside a rectangle put on the structure (bridge) to measure the displacement or vibration.

For calibration purpose, its size should be precisely known. There is a special version with light function for dark time or cloudy weather. The camera is a digital type camera with 640x480 resolution and IEEE1394 interface with fair portability. To cover high frequency vibration, Basler A602f is selected. This camera has a capacity reaching 100 FPS (frames per seconds).

Software

The Software has been developed using Microsoft Visual C++ with MFC (Microsoft Foundation Class) and Balser SDK (Software Development Kit)/API (Application programming Interface) [Basler]. The GUI (Graphic User Interface) is shown in Figure 2. The GUI is composed among others of an image section for real image display, a graph section to display displacement/vibration history, a command button for calibration and measurement, and setup and utility.

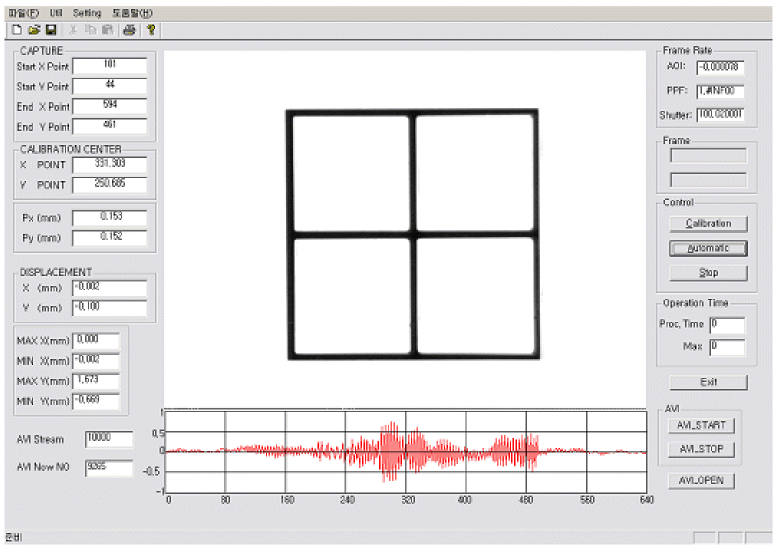

Figure 2. GUI for the system setup and measurement

Algorithm

Let us denote the image as $g(i, j)$, where $i = 1,2,3,\ldots,M$, $j = 1,2,3,\ldots,N$ and $M \times N$ is the size or resolution of the image. After a basic preprocessing, each pixel data is summed along the *x* or *y*-axis to generate projection data as shown in Figure 3.

To find the center of the line, the valley data is curve-fitted to a second-order polynomial in Equation (1) and the center of the parabola is given as in Equation (2).

$$f(x) = ax^2 + bx + c \quad (1)$$

$$x_c = -\frac{b}{2a} \quad (2)$$

For calibration, 2 corner points of the target mark are found, then the calibration data (pixel to mm ratio) is calculated as

$$P_x = \frac{L_x}{C_1 - C_3} \tag{3}$$

where L_x is the target's *x*-directional size, and C_1 and C_3 are the first and third center points in pixel.

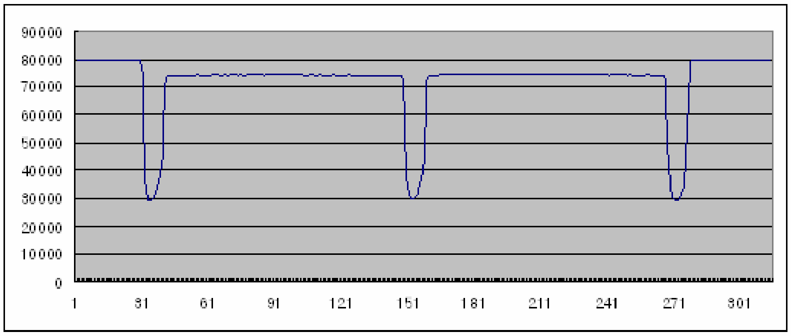

Figure 3. Projection data shape

CHECK TEST OF THE DEVELOPED PRODUCT

Laboratory check test

(1) Laboratory test on a prototype bridge

A prototype bridge was manufactured at first in order to perform laboratory tests to check the performances of the product. Figure 4 illustrates the prototype bridge used for laboratory tests.

A laser sensor and DAQ (Data Acquisition) were installed on the prototype bridge for comparative tests. In addition, the AMP receiving the signals presents capacity of 0.1V/mm and outputs voltage of ±4V for a displacement of ±40mm. This output is used as reference value for comparison through the DAQ.

Figure 4. Prototype bridge for the performance check test

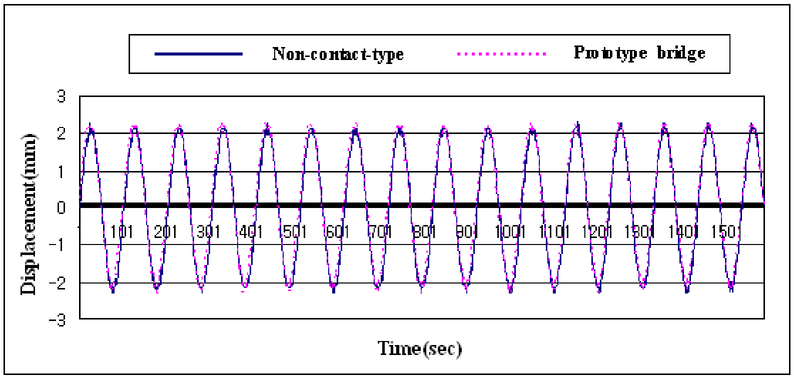

Figure 5. Comparison of the prototype bridge and “non-contact” measurement results

(2) Laboratory test on full-scale bridge

After completion of the applicability test on the prototype bridge, the test has been performed on a full-scale 20m CFT girder bridge at the Korea Institute of Construction Technology. The measuring distance was 30m. Figure 6 shows a view of the measurement performed on the CFT girder bridge. Figure 7 plots a comparison of the deflections measured in the CFT girder bridge.

(a) View of test on the CFT bridge

(b) Installation of the luminous target

(c) “Non-contact” displacement measurement

Figure 6. Full-scale CFT girder bridge for performance check

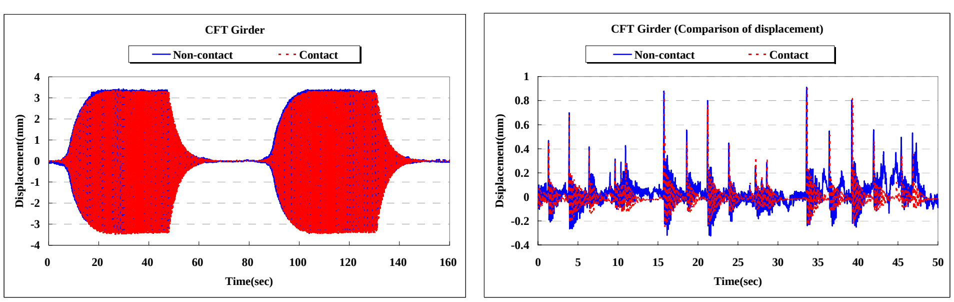

Figure 7. Comparison of contact and non-contact measurement results

Applicability test on site

As explained in the previous section, the laboratory test of the product has been successfully completed. Thereafter, structures were selected for the verification of the applicability and easiness of use on field through comparison with former systems. The selected structures are Jangheung Viaduct, an ordinary road bridge located in the city of Yangju, Province of Gyeonggi, and Yeonjae Bridge, a high-speed railway bridge located in Osong, Province of Chungbuk.

(1) Test on road bridge structure (Jangheung Viaduct)

Jangheung Viaduct, located in the city of Yangju, Province of Gyeonggi, is a 7-span continuous composite ordinary road bridge. Figure 8 depicts the installed contact and “non-contact” displacement measuring systems. The measurements were performed at distances of 20m and 108m.

Figure 9 compares the results measured by the contact and “non-contact” displacement sensors. The solid line represents the data measured by the “non-contact” sensor and the dashed line represents the ones measured by the “non-contact” sensor.

Figure 8. Contact and non-contact sensors installed on Jangheung Viaduct

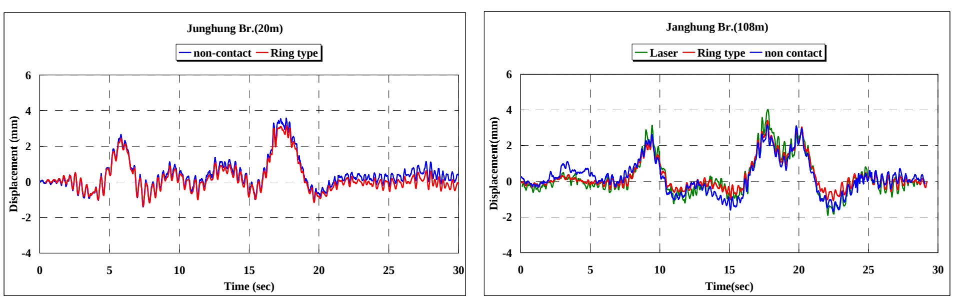

Figure 9. Comparison of the measurement results of the contact and non-contact sensors

(2) Test on high-speed railway bridge structure (Yeonjae Bridge)

Yeonjae Bridge, located in Osong, Province of Chunbuk, is a 2-span continuous PSC box girder bridge crossed by the KTX (Korean Express Train). Figure 10 shows a view of Yeonjae Bridge, the installed contact-type displacement sensors, and the installation of the nighttime target. The performance check tests in Yeonjae Bridge were performed at distances of 50m, 100m, 150m and 200m for a comparative check so as to allow comparison with the former contact-type displacement measurement system. Figure 11 compares the graphs obtained by the contact-type and non-contact displacement systems according to the distance. The solid line represents the data measured by the “non-contact” sensor and the dashed line represents the ones measured by the “non-contact” sensor. Results revealed that the error occurring in the contact-type displacement sensor increases with the distance. This error can be explained by the fact that the effect of the wind increases proportionally with the distance.

(a) View of Yeonjae Bridge (b) Installation of contact-type displacement sensor (c) Installation of the luminous target

Figure 10. Contact-type and non-contact-type displacement measurement systems installed in Yeonjae Bridge

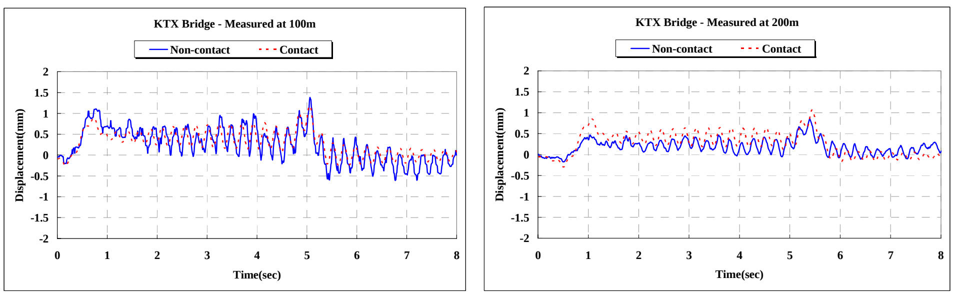

Figure 11. Comparison of contact and non-contact-type measurement data

CONCLUSIONS

This study developed an independent non-contact-type vibration measurement system including a digital signal processor (DSP) chip and image recording equipment enabling remote monitoring, which automatically measures and stores the vibration of structures by identifying a target stuck on the structure using image processing technique. The exploitation of the developed system presents the advantages of easy installation and portability compared to former contact-type measurement systems as well as extreme precision.

The developed measurement system offers stable performances with a sampling rate of 100Hz up to a distance of 200m. A nighttime target has also been developed so as to be free of weather effects. Further studies intend to reduce the error occurring with longer measurement distances. Moreover, the performances will also be enhanced by shifting the current single-measurement point to multiple measurement points.

At final completion of this study, it is expected that efficient measurement will be realized by satisfying the following requirements: high-speed multiple points and simultaneous measurement, nighttime measurement, remote sensing, and fast response speed.

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