A PRELIMINARY STUDY ON INVESTIGATION OF SEISMIC RESPONSE OF HIGH-RISE BUILDINGS USING A VISION-BASED METHOD BASED ON FULL-VIEW IMAGE

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ABSTRACT: A novel method is proposed to investigate seismic response of high-rise buildings. It is based on an image processing technique using successive full-view images of video shot by a single camera. Multiple points including reference points at the ground level in shot images with a full view of the building are adopted to acquire the displacement response at each point. A time history displacement response can be obtained from video shot successively during the whole earthquake time. The natural frequency can be easily identified from the obtained displacement response. Finally, an application of this method has been carried out on a video shot by Japan Broadcasting Corporation (Nippon Housou Kyoukai) of high-rise buildings at Shinjuku, Tokyo during Off Pacific Coast Tohoku Earthquake on 11th March 2011.

Key Words: Vision-based method, Full-view image, Seismic response, Displacement measuring, Video observation

INTRODUCTION

Seismic response records of structures from real earthquake are very important for exploring structures' characteristics, and also for structural health monitoring. In fact, the acceleration and velocity signals can be easily acquired by installing corresponding devices such as accelerometers and velocimeters. However, displacement measurement of existing building is quite difficult because traditional displacement sensors, such as linear variable differential transformers (LVDTs) and dial gauges, requires stationary fixed position as the measurement reference. The difficulty of providing reference point has become the crucial problem for displacement measurement. Although, displacement can be obtained by double integration of acceleration data using acceleration-based technique, the result is not stable because of the bias especially in low-frequency contents (Park, 2005).

To overcome this problem, the vision-based method has been developed and studied by researchers through decades especially in bridge measurement. Stephen (1993) proposed a visual tracking system in the measurement of deck displacement of the Humber Bridge in the UK. A transputer network was adopted to realize parallel tracking which can deal with multiple moving objects in real-time. User-selected templates are extracted from the initial frame and a template matching operation applied repeatedly to track the motion of multiple, independent objects at video frame rate. Using visual tracking system can effectively observe the very low frequency movement of the bridge. Olaszek (1999) has developed a viewing system for investigation of the dynamic characteristic of bridges with an additional reference system. The reference point can be used to exclude the effect of translational

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movement at image capturing camera but not rotational movements. It was possible to measure the displacement of typical bridge structure spans under dynamic and static loads. Wahbeh (2003) proposed a vision-based approach for obtaining direct measurements of the absolute displacement time history at Vincent Thomas Bridge using a highly accurate camera with a resolution of 520 lines and a capacity of 450digital zoom. Two high-resolution red lights (LED) are adopted as the targets mounted on a black steel sheet with 28 inches high and 32 inches wide. Optical data reduction and a nonlinear Gaussian regression curve fit were used to obtain the highest intensity of the red spot and determine the center of the spot, respectively. Lee (2006) proposed a digital image processing techniques used for the real-time measurement of dynamic displacement of flexible bridges. A target panel of known geometry was used as the measurement point whose displacement is calculated using the image processing techniques using texture recognition algorithm. Two field tests showed that this method can be successfully utilized to measure the displacement of a flexible bridge, and also highly cost effective and easy to implement. Park (2010) supposed a vision-based displacement measurement method for high-rise building structures using partitioning approach. The whole structure is divided into several parts to overcome the visibility range of optical devices. The test results showed that the displacement measurement error is less than 0.5%.

In the previous studies, the camera is all seemed as fixed thus difficult to be used in the seismic response measurement. Even if an additional reference point (Olaszek, 1999) can exclude the rotational movements, the camera with a large zoom concentrating at the target point may lose the target when suffering a big earthquake vibration.

With the development of camera industry, highly accurate camera become possible thus can provide certain precision in a full-view image. On the other hand, the seismic investigation showed that a quite large response in structures had been occurred during a big earthquake such as the Off Pacific Coast Tohoku Earthquake (Cheng, 2012). Especially, the high-rise buildings experienced a long period vibration with big displacement amplitude for a long time. The large displacement can give us the possibility that even if the precision is relatively low in the full-view image, the displacement is also identifiable. These two reasons above provide the feasibility of the application of the full-view image into seismic response measurement.

In this study, a novel displacement measurement method based on a full-view image is proposed for investigation of seismic response of flexible structures such as high-rise buildings. The whole size of the building is shot in one image while the ground part is seemed as the reference in order to exclude the vibration of the camera including the translational and rotational movement.

THE PROPOSED METHOD

Introduction

Figure 1 adopted the high-rise building as an example shows the image of the proposed method. The black circle is chosen as the basic template point. Two reference points on the ground floor are used as the reference system to record the vibration of the camera from the earthquake including translational and rotational movement. Several target points which mounted on the floor whose displacement is interested are used for calculating the relative displacement between the target floor and the ground floor by excluding the camera movement recorded by the two reference points.

Camera movement excluding method

Figure 2 shows the camera movement represented by the two reference points. The translational movements of the midpoint of the two reference points are adopted as the camera translational movements. The change of the angle of the straight line connecting the two reference points is adopted as the camera rotational movements.

We assume the coordinates of the two reference point and the ith target point as (x_{R1}, y_{R1}),

(x_{R2}, y_{R2}) and (x_{Ti}, y_{Ti}), respectively. And use superscript "0" as the initial position, "k" as the k[th] frame of the recorded video. So the camera movement of each frame can be calculated as follows.

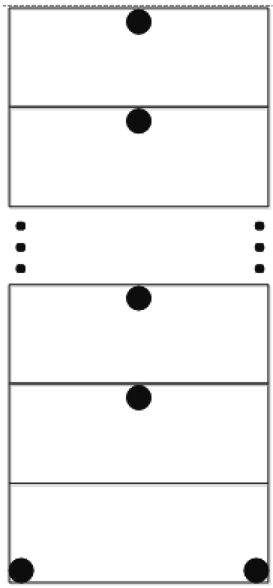

Figure 1. Full view image and target panel

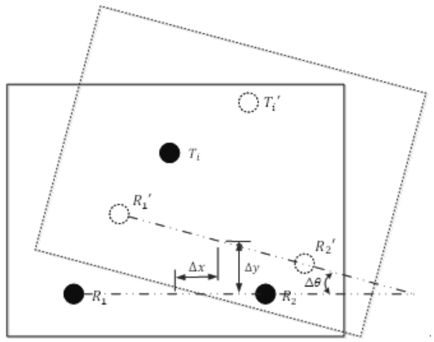

Figure 2. Camera movement by reference points

$$\Delta x^k = x_m^k - x_m^0 \tag{1}$$

$$\Delta y^k = y_m^k - y_m^0 \tag{2}$$

$$\Delta \theta^k = \arctan \left\{ \frac{tan\beta - tan\alpha}{1 + tan\beta tan\alpha} \right\} \tag{3}$$

In which, Δx^k, Δy^k and $\Delta \theta^k$ are the horizontal displacement, vertical displacement and angle movement at the k[th] frame, respectively. x_m^k and y_m^k are the coordinate of the midpoint of the two reference points. $tan\alpha$ and $tan\beta$ are the inclination angle of the straight line connecting the two reference points at the initial position and the k[th] frame, respectively. It can be calculated by the following formula.

$$\tan\alpha = \frac{y_{R2}^0 - y_{R1}^0}{x_{R2}^0 - x_{R1}^0} \tag{4}$$

$$\tan\beta = \frac{y_{R2}^k - y_{R1}^k}{x_{R2}^k - x_{R1}^k} \tag{5}$$

Then, the excluding of the camera movement for the target point can be done as follows.

$$x_{Ti}^{k\,\prime} = \left(x_{Ti}^k - x_m^0\right)\cos\left(-\Delta\theta^k\right) - \left(y_{Ti}^k - y_m^0\right)\sin\left(-\Delta\theta^k\right) + x_m^0 \tag{6}$$

$$y_{Ti}^{k\,\prime} = \left(y_{Ti}^k - y_m^0\right)\cos\left(-\Delta\theta^k\right) + \left(x_{Ti}^k - x_m^0\right)\sin\left(-\Delta\theta^k\right) + y_m^0 \tag{7}$$

Where, $x_{Ti}^{k}{}'$ and $y_{Ti}^{k}{}'$ are the coordinate of target point whose camera movement has been excluded. Finally, the relative displacement of each target point to the ground floor can be calculated by the following formula.

$$dx^{k} = x_{Ti}^{k}{}' - x_{Ti}^{0} \tag{8}$$

$$dy^{k} = y_{Ti}^{k}{}' - y_{Ti}^{0} \tag{9}$$

Implementing procedure

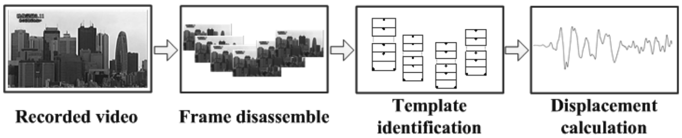

Figure 3. The procedure of this measuring method

Figure 3 shows the procedure of this vision-based measuring method. There are mainly three steps:

Firstly, the recorded video should be disassembled frame by frame, and normally, the frame rate is 25 FPS for PAL standard and 30 FPS for NTSC standard. The frame rate of a normal digital video can reach about 100 FPS, and a high-speed camera can reach up to 1000~10000 FPS. However, a high-speed frame rate device will increase the cost and the difficulty of data storage. Thus a normal speed less than 100 FPS is considered highly cost-effective and high enough to obtain the structural dynamic properties from the result because of the long period of the high rise buildings.

Secondly, the so called template identification is implemented to each image. The black spots located in the white background can be identified from the black-and-white image. Then the coordinate of the center of each spot can be determined using a nonlinear Gaussian regression curve fit as Wahbeh (2003) did.

Finally, the displacement response can be calculated using formula (1)~(9) above. If the precision is good enough, a time history result can be obtained. Otherwise, we can get part of the response or only the peak amplitude which will be illustrated later.

AN IMCOMPLETE APPLICATION

The vibration of the high-rise buildings at Shinjuku (Figure 4) during the Off Pacific Coast Tohoku Earthquake on 11th March 2011 had been recorded by Japan Broadcasting Corporation (Nippon Housou Kyoukai) from NHK Broadcasting Center at Shibuya, Tokyo (NHK, 2012). The high-rise buildings had been recorded as full-view image in the video and we analyzed 10 of them whose seismic responses were relatively large enough to be identified.

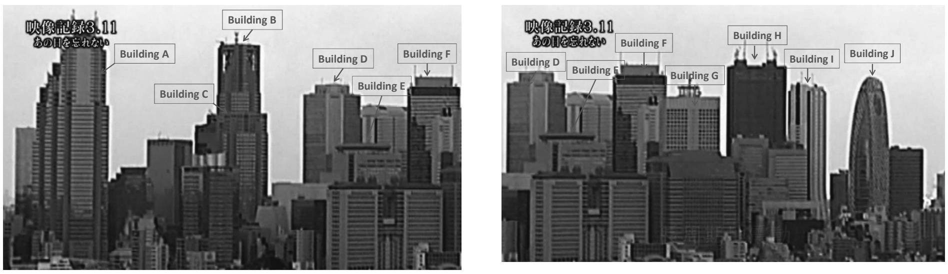

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Figure 4. The high-rise building group at Shinjuku, Tokyo

Because the camera which shot this video is used for the temperature observation, the pixel of the image is low (856×480), the frame rate is 3 FPS, and also we had not set the template on the structure. The proposed method in this study can't be applied on this video analysis completely. The following simplifications had been taken into this analysis. Firstly, use the existing remarkable things on the structurers such as windows, edge of the wall, as the template of the reference point and target point. Secondly, because the camera movement had been extruded by handwork, only two point, top and bottom of the building, are adopted to only extrude small residual translational movement and obtain the displacement at the top of the building. Thirdly, only the peak displacements within this video time are resulted instead of time history result because it is extremely difficult to recognize the displacement frame by frame without prior template under a low pixel.

Table 1. The response of the high-rise buildings at Shinjuku

Name	Height(m)	Floor Count	Structural Style	Period(s)	Peak-to-peak Amplitude(m)
Building A	235	52 B5	Steel ; BG: SRC, RC	6.9	2.0
Building B	243	48 B3	Steel ; BG: SRC	5.5	1.6
Building C	163	34 B3	Steel ; BG: SRC	4.1	1.0
Building D	210	52 B4	Steel ; BG: SRC, RC	4.9	1.9
Building E	122	30 B3	Steel ; BG: SRC	4.4	0.7
Building F	210	55 B3	Steel ; BG: SRC	6.2	1.2
Building G	165	32 B3	Steel ; BG: SRC	4.5	1.8
Building H	216	54 B4	Steel ; BG: SRC, RC	5.5	0.8
Building I	193	43 B6	Steel ; BG: SRC, RC	4.8	1.0
Building J	204	50 B3	Steel ; BG: SRC, RC	4.4	1.0

Table 1 shows the result of this video analysis, the displacement response of the high-rise buildings at Shinjuku. In which, the period and peak-to-peak displacement amplitude of building B and C from the earthquake record has been opened by Tokyo Local Finance Bureau (2011), 5.4s, 1.3m and 4s, 1.22m, respectively. The period recognized from the video keep a better precision than displacement although the frame rate is low.

CONCLUSIONS

A novel method based on the full-view image for the investigation of seismic response of high-rise buildings is proposed. The time history displacement response can be obtained from video shot successively during the whole earthquake time. The proposed method is elaborated here including the camera extruding method and the implementing procedure.

Finally, an incomplete application to a precious earthquake video with low pixel is carried out. The result showed that we can get period and displacement at a certain precise level even if the original video has a low precision. The practicality and simplicity are advantages of this method, and a real application to flexible structures is in prospect.

On the other hand, with the development of the personal digital devices, such as digital camera, smart phone, the video shooting becomes more convenient. Especially after the Off Pacific Coast Tohoku Earthquake, it has been an obvious phenomenon that lots of videos of building vibration during earthquake were recorded and shared with others by network. The proposed method which is easy to implement is also expected to do contributions by dealing with those existing videos.

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