Pixel-Wise Vision-based Approach for Vibration Monitoring from Repurposed Surveillance Videos: Validation on a Full-Scale Building

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ABSTRACT: In this paper, a target-free vision-based vibration monitoring method is used to extract the predominant period of the benchmark full-scale five-story structure tested on the large high performance outdoor shake table at the University of California San Diego as part of the building nonstructural components and systems project. The method uses Kanade-Lucas-Tomasi tracker to extract the pixel-based relative displacement time history of the structure by tracking robust features within video footage recorded by surveillance cameras within the building. Then, the predominant frequency of the structure is estimated using a basic output-only system identification method, frequency domain decomposition.

Test Structure and Measured Data

The building nonstructural components and systems (BNCS) project consists of a full-scale five-story reinforced-concrete building (see Figure 1) tested at the University of California San Diego. This building was instrumented with analog sensors as well as consumer-level closed-circuit cameras and tested in base-isolated and fixed-base configurations, under different earthquake ground motions. In this study, the videos recorded by the cameras during six independent tests, under six different earthquake ground motions described in Table 1 – downloadable on the NHERI DesignSafe-CI Data Depot [1] – are processed to extract the structural predominant period in the fixed-base configuration. The videos are 25 fps at a resolution of 1280×720, containing "UC San Diego" watermark and black sidebars. More details on the BNCS building and project can be found in Ref. [2].

SHM Methodology and Results

Methodology

Computer vision-based vibration monitoring methods are widely used to tackle the practical drawbacks of the traditional accelerometer-based measurements. Most of the vision-based monitoring approaches are based on camera installation outside the structure to capture the structural response. Despite good performance of such methods, practical and technical considerations cause some limitations in their general application. To overcome these issues, Harvey and Elisha [3] proposed a vision-based monitoring method using pre-existing surveillance cameras within the buildings. In their method, pre-installed high-contrast grid of points was defined as the target points and the relative pixel displacements were extracted by tracking the points in all the video frames. In the next step, a quadratic mapping was used to convert the structural displacement from pixel coordinates to engineering units. In the present study, a modified version of this method is utilized for vibration monitoring using surveillance cameras.

At first, the RGB image sequences are converted to grayscale format which eliminates the hue and saturation information even though the luminance of the images is retained. Then, robust features in the selected region of interest (ROI) in the first image of footage are identified using speeded-up robust features (SURF) algorithm [4]. Therefore, the trackable features are automatically selected and the proposed method is target-free. The features are then tracked for all the remaining frames of the footages using the Kanade-Lucas-Tomasi (KLT) feature-tracking algorithm [5] to extract the relative pixel motions. Note that since the pixel-wise drifts represent the relative motion between the camera attachment point and the objects existing in the field of view, a wealth of information about the underlying structural system can be returned by analyzing these drifts even if the pixel-to-physical calibration is unknown. This idea is examined in the present study to estimate the predominant period of the structure from pixel-wise drifts using ARTeMIS Modal (v5, Structural Vibration Solution A/S, Denmark).

Results and discussion

The proposed method is employed for vibration monitoring of the BNCS building tested in fixed-base under different earthquake excitations introduced in Table 1. For each case, a typical footage associated with one of the cameras installed in the structure was selected and the robust trackable features were automatically identified using SURF algorithm. Figure 2 shows the robust features inside the ROI in the first frame of the footage captured during the fifth test. It should be mentioned that the ROI was selected to be large enough to avoid unnecessary user judgement in selecting the robust trackable features. In the next step, the pixel-wise drifts associated with all the robust features were extracted for each test. Videos were processed using KLT method and the pixel drifts were extracted in both x and y (pixel) directions. Not only pixel drifts in x and y directions, but also their projection on the main principle coordinate using principal component analysis (PCA) were used to estimate the predominant period of the structure by means of the frequency domain decomposition (FDD) algorithm in ARTeMIS Modal. The obtained results – which are the average of the estimated periods from each of the tracked features for each test (removing any outliers) – are summarized in Table 1. This table also contains the structure's period estimated by time domain optimization (TDO) method in Ref. [2].

Figure 1. BNCS building on University of California San Diego's outdoor shake table.

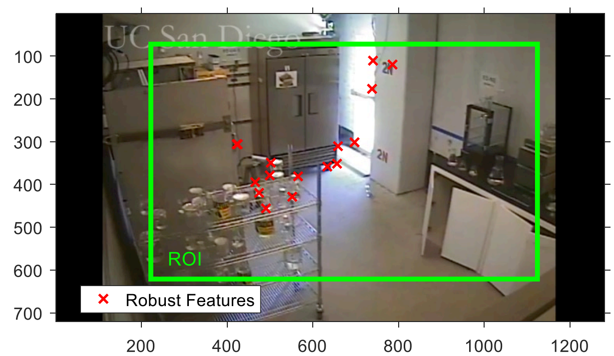

Figure 2. Robust features in the region of interest (ROI) for FB-5:DEN67.

Table 1. Details of the tests and the estimated fundamental period (sec.).

Earthquake [event/site/scaling (%)]	Test name	TDO method [2]	Vision-based method		
			x	y	PCA
1994 Northridge/Canoga Park/100	FB-1:CNP100	0.87	0.96	1.49	0.96
1994 Northridge / LA City Terrace/100	FB-2:LAC100	0.96	0.99	0.74	0.99
2007 Pisco (Perú)/Ica/50	FB-3:ICA50	1.09	1.20	1.15	1.20
2007 Pisco (Perú)/Ica/100	FB-4:ICA100	1.18	1.39	1.39	1.39
2002 Denali/TAPS Pump Station/67	FB-5:DEN67	–	2.26	1.98	2.06
2002 Denali/TAPS Pump Station/100	FB-6:DEN100	–	2.11	2.53	1.95

Generally, the predominant period of the structure is about 1 sec. Based on Table 1, the proposed method estimates the structure's period with an acceptable accuracy. Note that the excitations have been generated by unidirectional shake table, which roughly corresponds to the x direction. For this reason, the periods estimated from pixel-based drifts extracted in y direction are not as accurate. It should be mentioned that in this study the pixel-based drifts of the all robust features were used to extract the structural period. Although all the features are robust in terms of their properties in grayscale images, some of them have been selected on the nonstructural components (see the features in the left half of Figure 2) and their vibrations differ from the structure's dynamics. This issue can adversely influence the accuracy of the estimated periods and is one of main error sources for the reported results in Table 1.

Lessons Learned

A target-free method for structural vibration monitoring leveraging the videos captured by the pre-existing costumer-level videos distributed in the buildings was proposed. The method employed the KLT approach to track the automatically-selected robust features frame-by-frame in the recorded footage. The extracted pixel-wise drifts were then analyzed by the FDD algorithm to estimate the predominant period of the structural system. The method is beneficial from practical viewpoint, since there is no need to install new data acquisition units or target points. Moreover, it is computationally cost-effective since the pixel-based drifts are directly analyzed to extract the structural period and there is no need to convert the data from pixel domain to the engineering units. The method was validated by a studying the videos captured from testing a full-scale five-story building on a large shake table and the structural dominant period was estimated with high level of accuracy in all the studied cases.

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References

[1] T. Hutchinson, J. Restrepo, J. Conte, et al., Shake table testing of a five story building outfitted with NCSs (BNCS project) Dataset, Network for Earthquake Engineering Simulation (distributor). (2014).

[2] M.C. Chen, E. Pantoli, X. Wang, et al., Full-scale structural and nonstructural building system performance during earthquakes: Part I – specimen description, test protocol, and structural response, Earthq. Spectra. 32 (2016) 737–770. https://doi.org/ 10.1193/012414EQS016M

[3] P.S. Harvey, Jr., G. Elisha, Vision-based vibration monitoring using existing cameras installed within a building, Struct. Control Health Monit. 25 (2018) e2235. https://doi.org/10.1002/stc.2235

[4] H. Bay, A. Ess, T. Tuytelaars, L. Van Gool, Speeded-up robust features (SURF), Comput. Vis. Image Underst. 110 (2008) 346–359. https://doi.org/10.1016/j.cviu.2007.09.014

[5] C. Tomasi, T. Kanade, Detection and Tracking of Point Features, Int. J. Comput. Vis. (1991).