Computer Vision-based Displacement Measurement Method With Arbitrarily Positioned Camera

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ABSTRACT

Displacement is broadly used in structural health monitoring as a meaningful indicator of structural status. Measuring structural displacement using conventional devices such as the linear variable differential transformer is challenging due to practical issues such as equipment inaccessibility, insufficient measurement accuracy, or expensive system cost. Recently, computer vision-based displacement measurement methods have been developed to build high field applicable measurement system. However, the existing computer vision-based displacement measurement techniques still have practical issues such as absence of camera installation point, marker attachment, or light-induced error. This paper presents a computer vision-based displacement measurement system focusing on solving camera positioning issue. The proposed method adopts homography transform to allow cameras to be positioned at arbitrary point. A laboratory scale experiment was conducted to verify accurate displacement measurement of the proposed method with the arbitrarily positioned camera.

1. INTRODUCTION

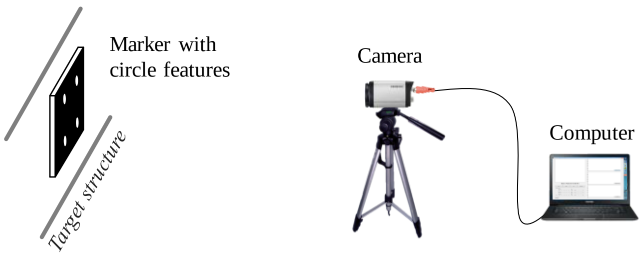
Displacement is broadly adopted in structural health monitoring (SHM) as a meaningful indicator of structural status. Load carrying capacity of a civil structure is directly reflected in the displacement. To monitor the health of a civil structure rigorously and precisely, displacement should be involved in the analysis process. However, measuring structural displacement using conventional devices such as the linear variable differential transformer is challenging due to practical issues such as equipment inaccessibility, insufficient measurement accuracy, or expensive system cost.

Camera is utilized as a measurement device with computer vision techniques to overcome the practical issues. Structural motion video, which is taken by a camera, is firstly processed to detect features to be tracked. The detected features location in the image plane are then transformed to the metric displacement. Previous studies showed high accurate measurement results in the field application with adequate camera position, however, field condition does not provide appropriate installation point for the cameras.

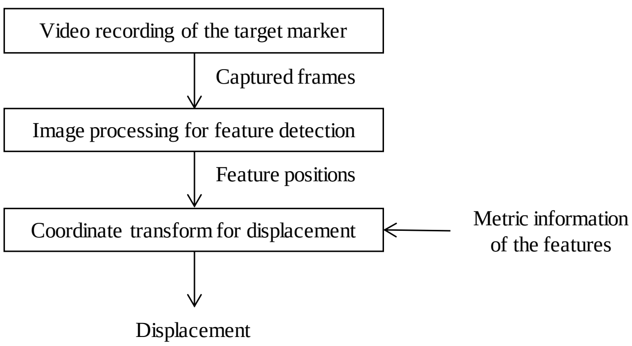
This paper proposes a computer vision-based displacement measurement system using a homography transform. The proposed method allows cameras to be placed at arbitrary location. The proposed method is compared with the conventional method experimentally.

2. PROPOSED METHODOLOGY

As shown in Figure 1, computer vision-based displacement measurement methods typically consist of hardware and software components. The hardware part can be prepared with a commercial camera, a computer for data acquisition and processing, and a user-defined target marker to build a highly cost-effective system. As shown in Figure 1(a), the marker consists of a panel with noticeable features, such as circles or corners, and it is attached to a structure where displacement is calculated. The marker movements are recorded by the camera and simultaneously transferred to the computer. The computer calculates the displacement from the transferred images via software process described in Figure 1(b). The software process first performs image processing to detect the features in each captured frame and in turn obtains the coordinates of the features in the image. Note that these coordinates are called image coordinates, which represent the locations of certain points in the image. From the first image scene, the image coordinate of the features and the corresponding physical coordinates within the marker plane are combined to build the coordinate transform between the image and the marker. Here, the physical coordinates are the metric information of the features in the marker plane, which are informed when designing the marker. Using the coordinate transform, the incoming image coordinates are converted to physical coordinates indicating the time history of a structural displacement.



(a) Hardware component



(b) Software component

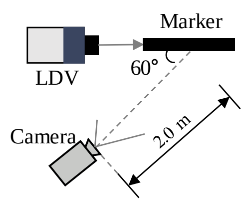
Figure 1. Vision-based displacement measurement approaches configuration

In vision-based displacement measurement systems, appropriate coordinate transform should be selected to allow cameras to be placed at arbitrary points. Affine transform, which is adopted by Lee and Shinozuka (2006), causes error when camera is placed aside from the marker plane. In this camera position, image is affected by the perspective projection which causes exaggerated movement for the closer objects and reversely to the further ones. Thus, more appropriate coordinate transform is required for cameras to be placed at any point.

This paper proposes homography-based displacement measurement system. Homography is a well-known computer vision technique that maps two planes in the same projective space (Hartley & Zisserman, 2003). Two planes in the vision-based measurement system are marker plane and image plane. Regardless of the relative position between the marker and the camera, metric displacement of the marker is exactly transformed from the image coordinates of the feature points. Thus, the proposed method allows camera to be arbitrarily positioned, which enhances field applicability.

3. LABORATORY SCALE EXPERIMENT

The accuracy of the proposed method is verified in the laboratory scale experiment. Experimental setup is shown in Figure 2. The marker is placed on a shaking table vibrating at 1 Hz. Camera is placed aside from the marker plane with 60°. LDV is also installed for the reference displacement. As shown in Figure 2(b), left two circles are magnified due to perspective projection.

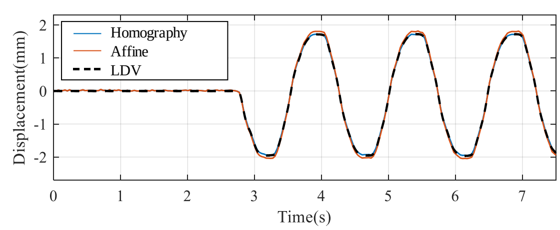


(a) Schematic view of experimental setup

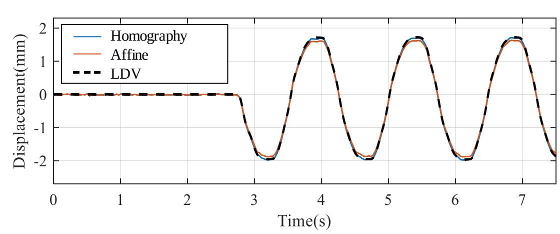
(b) First frame from the camera

Figure 2. Laboratory scale experiment setup.

The displacement at upper left circle and upper right circle is shown in Figure 3. As the left circles are located closer to the camera than right two circles, left circles are exagerated while right two circles become smaller. These effect are reflected in the displacement measurement using the affine transform. The displacement of the left circle shows increased amplitude while the right circle shows decreased one. While the afffine transform causes error depending on the circle's position, homography transform measures the exact displacement that shows great agreement with the displacement measured by the LDV. Thus, cameras can be placed at arbitrary point by using the homography transform.



(a) Displacement result of upper left circle



(b) Displacement result of upper left circle

Figure 3. Laboratory experiment results.

4. CONCLUSION

This paper presented a vision-based displacement measurement system using homography transform that allows camera to be placed at any point. Laboratory scale experiment was conducted with camera where the angle between the camera and the marker was 60°. The experiment verified that the homography is more reliable than the affine transform when camera is arbitrarily positioned.

ACKNOWLEDGEMENT

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BIOGRAPHIES

Junhwa Lee received his B.S. degree in urban and environment engineering from UNIST, Ulsan, Korea in 2016. He is currently a combined master's-doctoral student in urban infrastructure engineering at UNIST. His current research interests are structural health monitoring, structural dynamics, vision-based displacement measurement, smart sensor and sensor network, damage detection and system identification of civil structures.

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Sung-Han Sim received his B.S. and M.S. degrees in civil engineering from KAIST, Daejeon, Korea in 2000 and 2002, respectively, and Ph.D. degree in civil engineering from the University of Illinois at Urbana-Champaign in 2011. He currently works as an associate professor at UNIST. His current research interests are structural health monitoring, smart sensor and sensor network, damage detection, and system identification.