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Development of robust vision-based displacement measurement offering unconstrained camera position

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ABSTRACT

Displacement of a civil structure is versatile in structural health monitoring (SHM) in terms of structural safety analysis, damage detection, and system identification. Existing measurement techniques such as LVDT, LDV, and GPS encounter inevitable limitations in field testing such as difficulties in installing sensors, high equipment cost, or insufficient measurement accuracy. Computer vision-based approaches provide a cost-effective and practical alternative that can potentially address the issues in the displacement measurement. While the vision-based approaches in the literature were proven to accurately measure displacement responses in civil engineering applications, camera installation locations have not been discussed. This paper presents a vision-based displacement measurement system that enables unconstrained camera positions. Laboratory-scale validation shows displacements can be reliably measured when the camera is arbitrarily positioned.

1. INTRODUCTION

Structural displacement serves as an important indicator that frequently adopted in the structural safety analysis. Large displacement in a civil structure is caused by various reasons such as structural degradation or exposure to unexpected loads. To prevent hazardous structural disasters, certain levels of acceptable displacement are set in the most building codes as a safety indicator. On the other hand, displacement measurement of a large civil structure by means of commonly used measurement devices such as LVDT, GPS, and LDV meets difficulties in the field testing such as arduous sensor installation, insufficient measurement accuracy, or high equipment cost.

To overcome these difficulties in general devices, computer vision is introduced in

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the field of displacement measurement. The vision-based measurement system utilizes a remotely positioned camera with image processing that calculates displacement from the captured video. The performance has been proved in the previous research providing acceptable measurement accuracy with cost effective camera systems. However, the accuracy of the displacement measured by arbitrarily positioned camera has been unverified.

This paper presents two different approach of vision-based displacement measurements that enables unconstrained camera positions. One approach is affine transform based measurement (Lee 2006) that uses four points in average sense. The other is homography transform based measurement (Lee 2014) with one point. A laboratory scale experiment was conducted to verify two vision-based displacement measurement approaches' robustness to the camera position.

2. VISION-BASED DISPLACEMENT MEASUREMENT SYSTEM

Vision-based displacement measurement system typically consists of a marker, a camera, and a computer (see Fig. 1). A marker is a specially designed plate to be recorded by a camera. Video stream of the marker's movement captured by a camera is transferred to the computer in real time. The transferred video stream is then interpreted as structural displacement through image processing in the computer. From each captured frames, feature points are firstly searched by feature detection algorithms such as Harris corner detection or centroid detection. The searched points combined with pre-known marker dimension are used to calculate displacement.

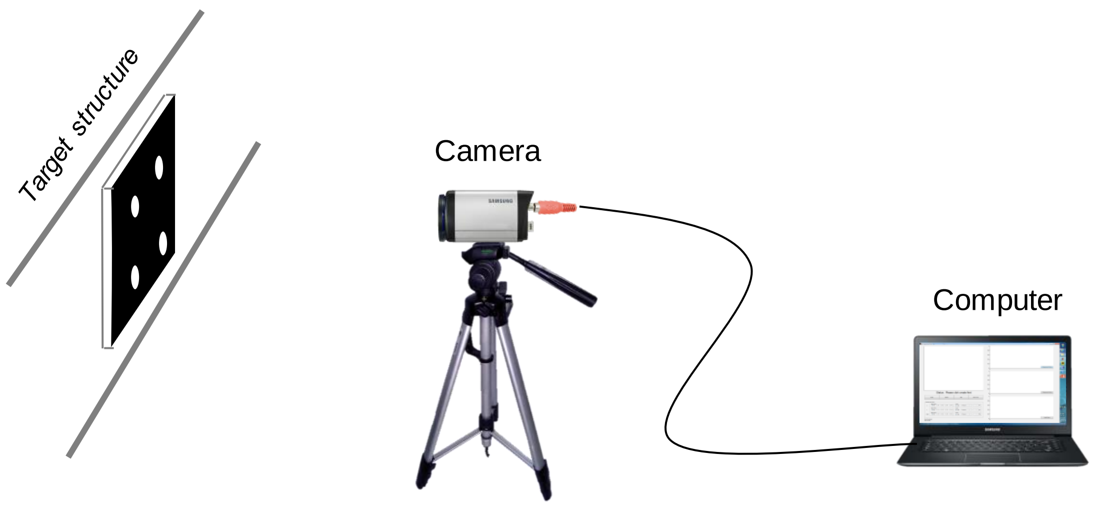


Fig 1. Component of general vision-based displacement measurement

The vision-based displacement measurement system can lead restriction on the available camera positions depending on the choice of coordinate transform method. In this paper, two coordinate transform methods, which are affine transform and homography transform, are discussed in terms of the camera positioning issue. Affine transform is a linear mapping between two planes that nonlinear behavior, especially perspective projection, is disregarded. To reduce error caused by perspective projection, camera should be positioned perpendicular to the marker plane or four points should be averaged. On the contrary, homography transform accommodates perspective projection that enable to measure accurate displacement of one point in the marker with an arbitrarily positioned camera. Hence, to use camera in the field testing, the comparison between affine and homography transform at a different camera location needs to be verified.

3. LABORATORY-SCALE TEST RESULT

Accuracy of two coordinate transform methods are compared with three different camera positions. Experimental setup is illustrated in Fig. 2. Marker, designed with four white circles with black background, is set on the shaking table. Camera is positioned 2m apart from the target with three different angles: 25°, 45°, and 60°. LDV is set next to the marker for measuring ground truth displacement.

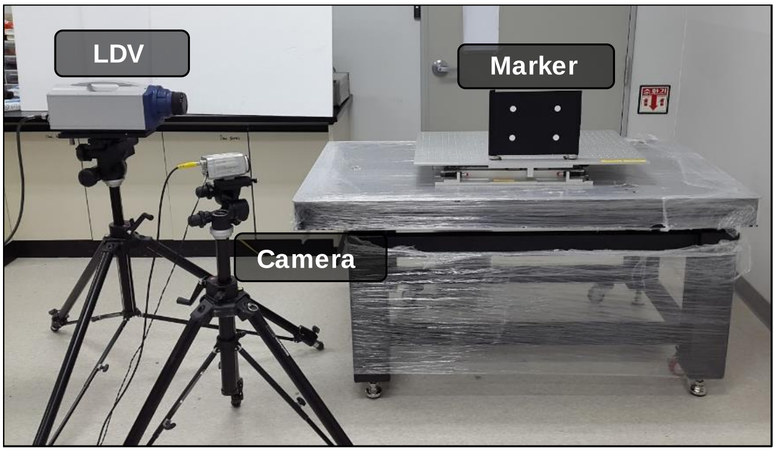
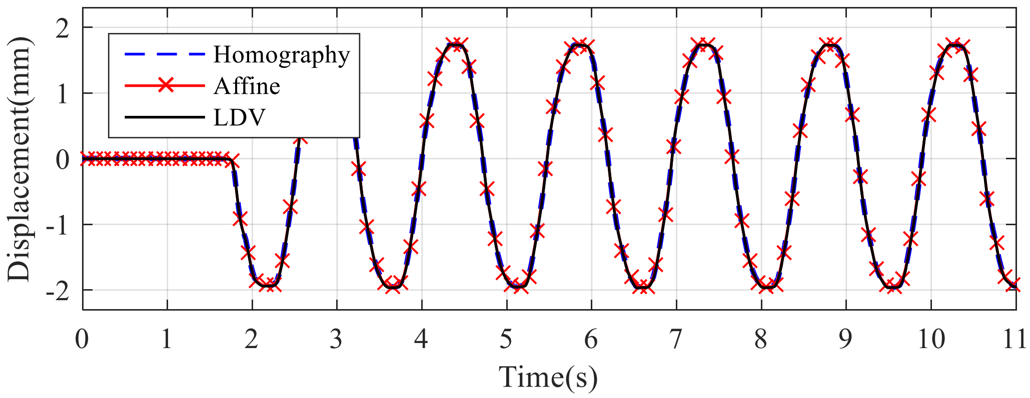


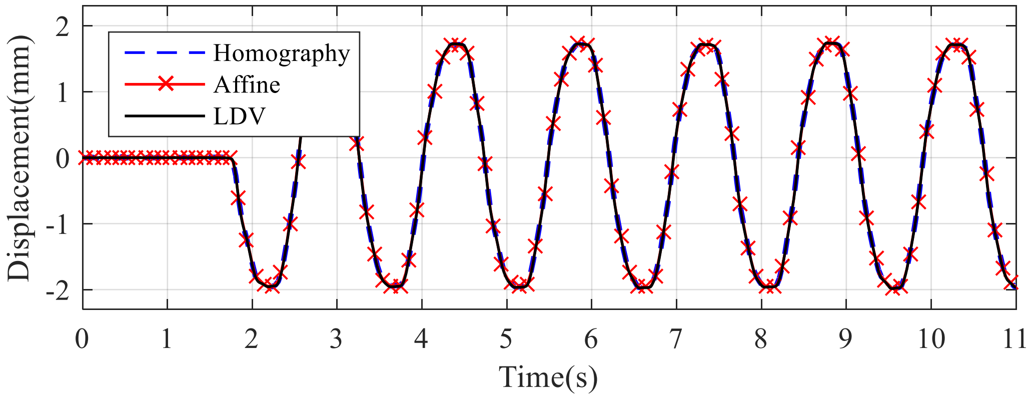
Fig 2. Laboratory scale experiment setup.

Displacement of four points in the marker are averaged to compare with LDV as shown in Fig. 3 (a)-(c). In this comparison, both affine-based and homograph-based measurement shows good agreement with LDV results. Since the displacement of the four different points are averaged, perspective projection effect becomes negligible in the both vision-based measurement results. Note that displacement using with one point in the affine-based measurement will be erroneous due to perspective projection.

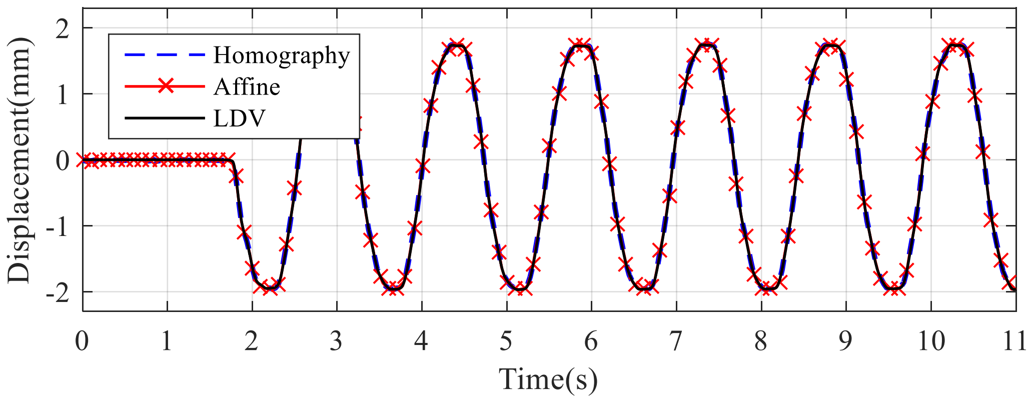
Consequently, camera can be positioned aside from the marker by using homography transform with one point or affine transform with four points.



(a) Result (Θ = 25°)



(b) Result (Θ = 45°)



(c) Result (Θ = 60°)

Fig 3. Laboratory scale experiment results.

4. CONCLUSIONS

Affine and homography transform in the vision-based displacement measurement system are discussed according to the available camera positions. While homography transform accommodate perspective projection, affine transform does not. Affine transform maps image plane linearly into the physical world; thus depending on the camera position perspective projection may result in scaling error. This camera positioning problem was solved by averaging displacement over four points. A laboratory scale experiment was conducted to verify robustness of the affine and homography transform to the camera position. Experimental results show that both affine transform with four points and homography transform with one-point measurement can be used in the application of large civil structures.

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