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Displacement Measurement of Burr Arch-Truss Under Dynamic Loading Based on Image Processing Technology

Yang Yang[1], Xiong (Bill) Yu[2*], Kamil Nizamiev[3], Dario Gasparini[4]

1 Research Assistant, Dept. of Electrical Engineering and Computer Science, Case Western Reserve University, Cleveland, Ohio, United States. E-mail: yxy379@case.edu
2 Associate Professor, Dept. of Civil Engineering, Case Western Reserve University, Cleveland, Ohio, United States. E-mail: xxy21@case.edu, Corresponding Author.*
3. Research Assistant, Dept. of Civil Engineering, Case Western Reserve University, Cleveland, Ohio, United States.
4 Professor, Dept. of Civil Engineering, Case Western Reserve University, Cleveland, Ohio, United States.

ABSTRACT

Video-based displacement measurement is a cost-effective way for remote monitoring the health of conditions of civil structures, especially for situations where accessibility is restricted and does not allow installation of conventional monitoring devices. The technical basis of video-based remote displacement measurement system is digital image analyses. Comparison of the images allow the field of motion to be accurately delineated. Such information are important to understand the structural behaviours including the motion and strain distribution. This paper presents system architecture and utilizes frame difference method to analyse the image sequences to extract the feature of motion. Firstly, the measurement spot is calibrated using a dark panel with known geometry. Then the system captures the full picture of structure with high image resolution using a commercial digital video camera. Meanwhile, the motion of the target is calculated using image processing techniques, which requires target tracking algorithms, calculation of the actual displacement using target geometry and the central point coordinates of moved pixels. The performance is demonstrated on a testbed of large scale burr arch-truss under dynamic loading process and validated using displacement sensor data. The results indicate that the proposed method can estimate the displacement of the bridge with sensitivity of 2.04 mm. With further refinement of system hardware and image processing software, it will be developed into a remote video based monitoring system for structural health monitoring of civil infrastructure to assist the diagnoses of its health conditions.

KEYWORDS: *SHM, displacement estimation, image processing technology, frame difference method*

1. INTRODUCTION

Health monitoring of bridge structures is important to ensure safety. They also provide data support for bridge preservation and maintenance decisions [1]. Many different sensing principles have been investigated for structure health monitoring (SHM) of various infrastructures [2]. They primarily are based on contact type sensors such as accelerometers, strain gauge, fiber optic sensors, piezoelectric based sensors and actuators, impedance based sensors, ultrasonic (lamb) wave sensors, and physical acoustic sensors, etc. [3]. Some of the limitations with these technologies include that they only provide localized information, and require a significant number of sensors to cover a broad area of the structure, besides they require access wires for power or data transmission [4]. Monitoring system based on video is promising to overcome some of these limitations. As a global measurement, it can map the strain and deformation of the structure remotely. By the use of zoom in lens, global scale and local scale measurement can be accomplished. Therefore, it has potential to be a cost-effective, reliable and noncontact method for field applications. One of the crucial component for accurate video-based SHM system is the image processing algorithm that determine the motion based on sequence of images. The brightness value (0-255) determine the pixel value in a grayscale image. And brightness depends on the amount of light captured by the image recording device. Therefore, this brightness value can be defined as two dimensional matrix transmitted from the photographed area of the subject to the image sensor through the optical lens. Measuring the displacement of certain structure starts with the movement direction of a specific point on the structure surface.

This paper reports the feasibility and reliability using image analyses algorithm to estimation large structure motion. A large scale burr arch-truss under dynamic loading in vertical direction is used as the testbed. The motion displacement is measured from video sequences using frame difference method, and compared with linear variable differential transformer (LVDT) sensor data.

2. EXPERIMENT

2.1. Burr Arch-Truss Testbed

The 11-feet-high, 44-feet-long reconstructed truss (shown in Figure 2.1) is known as a boxed pony truss – "pony" referring to its low height and "boxed" because the trusses were covered by wood. Two parallel hydraulic jacks produce the dynamic upward loading ranging from 0 – 50 kips at the bottom of the truss. Several reinforcing steel bars are holding the entire truss to make the load evenly distributed.

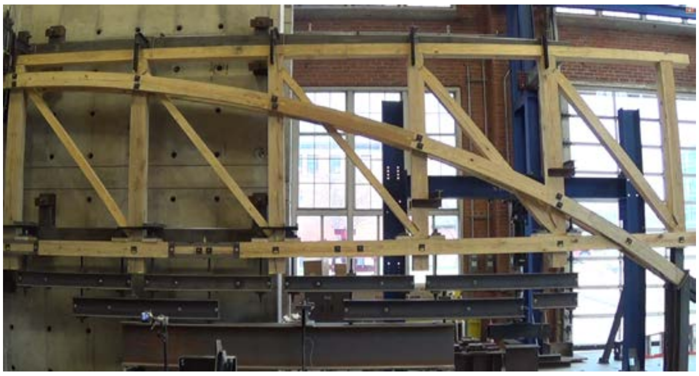


Figure 2.1 Burr arch-truss testbed

2.2. Camera Setup and Pixel Calibration

A digital video camera with variable focal length is setup in front of the truss. The distance is adjusted so that the camera can capture the full structure. The camera is fixed on an adjustable height tripod. The height of the camera is set to be the same as the dark panel in location 1 and location 2 (shown in Figure 2.2) and the lens is parallel with the structure. As the vertical displacement of the dark panel during the loading process is much smaller than the distance between truss and camera, therefore, it is safe to assume that the distortion of the dark panel in the image can be neglected when it is moving upward.

The aspect ratio and area of the pixels must be determined so that pixel measurements can be translated in to physical measurements by scaling [5]. A square object of know diameter (75 mm) was chosen for calibration because of easy access and higher contrast. Since the calibration object is contrived, there is no problem obtaining a good contrast image (see Figure 2). In this paper, area based calibration was adopt which use the width of square,

2.3. Image Preprocessing

A 167 seconds video section (in avi format) of wooden arch-truss during loading process is analysis. The video is firstly divided into 5000 frames with resolution of 3840×2160 in jpg format. To save the computation memory, only small part of the image is cropped as region of interest. The parsed image frames are then analysed in the subsequent studies.

Figure 2.3 shows the image preprocessing schematics of displacement measurement system. Five steps are incorporated in the processing procedure aiming to detect mark region, including grey scaling, median filter, binarization, denoise and fill holes. Detailed discussions are provided in the following section.

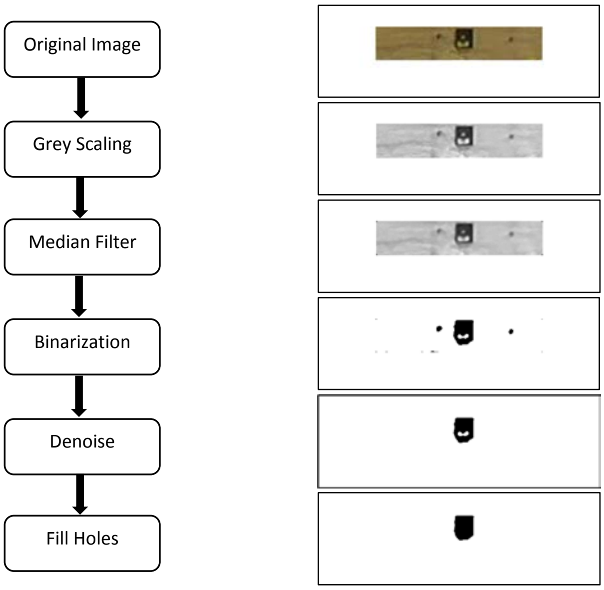


Figure 2.3 Image preprocessing flow chart

2.3.1. Grey Scaling

For accurately detecting dark panels in the original image sequences, a linear grey transformation is required to properly enhance images. Grey scaling [6] mapped the input grey level interval

$$H_B(t) = -\sum_{i=0}^{t} \frac{h(i)}{\sum_{j=0}^{t} h(j)} \log \frac{h(i)}{\sum_{j=0}^{t} h(j)} \tag{2.5}$$

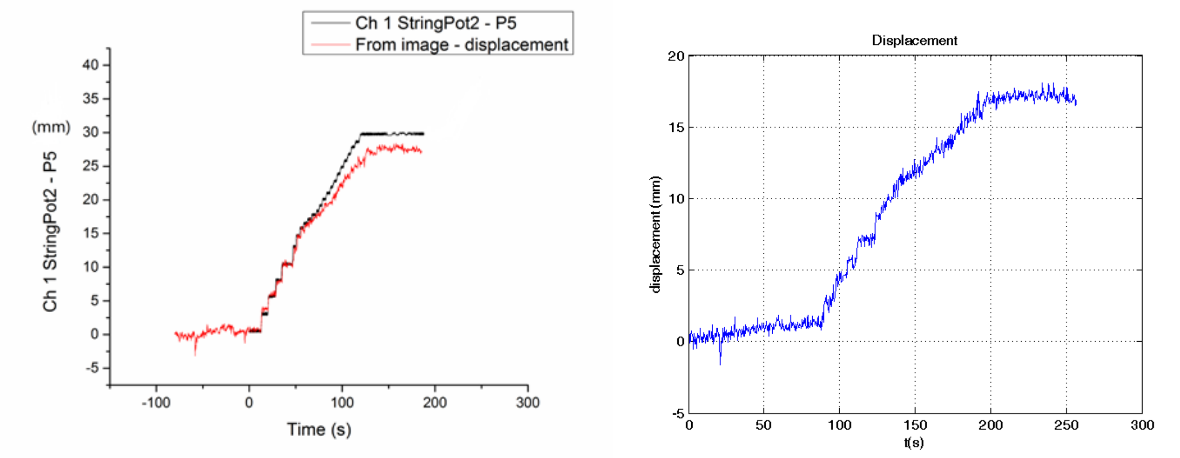
2.3.4. Dilation and Erosion

After binarization segmentation, there are normally some background noise or burrs in the edge of our objects following image processing. Therefore, morphological operations, dilation and erosion, opening operation and closing operation (Matlab R2012b), are performed to eliminate large background noise, small connected domains, isolated dots and also smooth boundaries of the object regions.

2.4. Frame Difference Method for Displacement Measurement from Video Signal

The frame difference method (FDM) [8] calculates the differences between frame at time t and frame at time t-1. In the differential image, the unchanged part is eliminated while the changed part remains. This change is caused by movement. Pixel intensity analysis of the differential image is needed to calculate the displacement of the moving target. This method is very efficient in terms of computational time and provides a simple way for motion detection between two successive image frames.

In this experiment, the input image for frame difference method was denoised binary images showing in Figure 2.3. Center pixel's coordinates of each square disc was calculated. And coordinates in y-direction can represent the displacement of model structural in vertical direction. Figure 2.4(a) shows the measurement result of location 1 based on frame difference method compared to LVDT displacement sensor data. Figure 2.4(b) shows the measurement result of location 2 based on frame difference method.



(a) (b)

Figure 2.4 Experiment results in location 1 and location 2

Figure 2.4 shows that the displacement of the arch-truss measured by sensor's data and calculated by frame difference method match very well. The senility is 2.04 mm/pixel, which indicates that the frame difference method based on digital image processing technology provides reasonable accuracy in measuring the vibration displacement of structure. Figure 2.4 also shows a little discrepancy of the displacement measurement between LVDT sensor based method and image based method. This is mainly due to assumption we made above which neglects the image distortion during the loading process.

Image based displacement measurement based on frame difference is easily performed and computational efficient. However, it suffers two major limitations. Firstly, the precision of this method to estimate velocity field is limited due to noise, shutter speed and image resolution. Second, this method only measure velocity in a certain direction (i.e. horizontal direction). It has difficulties in measuring complex movements.

3. CONCLUSION

Video-based monitoring system potentially provide reliable and economic solution for SHM applications. Particularly for situations where the access can be challenging (i.e. major bridges cross waterways). The performance of image processing algorithm is the key component in the successful application of such remote

SHM monitoring systems. This paper demonstrates the performance of frame difference method that obtain the motion from sequence of video images. A large scale testbed is set up on a burr arch-truss, where both traditional LVDT sensor and video-based system achieves similar accuracy in measuring the displacement field. With support of a robust and accurate image processing algorithm, a cost effective video-based remote monitoring system can be developed for monitoring and diagnose of structural conditions.

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