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Computer vision-based vibration identification for the roof mast of Saige Plaza Building

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SUMMARY:
On 18 May 2021, occupants in Saige Plaza Building felt significant building motion together with its roof masts caught in obvious vibration, which was recorded by a surveillance camera installed on the roof of Saige Plaza Building. We tried to process the video data by a deep learning augmented vision-based method (DAVIM) to analyse their vibration characteristics of masts. An indoor test has also been carried out to demonstrate that DAVIM can achieve high accuracy for structural displacement measurements in unfavourable practical situations, such as camera tilt and no artificial objects. By analysing the video data from May 15 to 22, the camera self-vibration component has been confirmed and filtered out in subsequent data processing. Considering the wind condition and masts self-vibration characteristics, the masts might experience the 4th mode vortex-induced vibration of 2.12Hz at most of the time. Two masts vibrated synchronously in-plane along opposite direction, with the south mast amplitude greater than the north mast.

Keywords: computer vision, vibration identification, Saige Plaza Building

1. INTRODUCTION

Located in Shenzhen, China, Saige Plaza building is a hybrid steel pipe and concrete structure. The main roof of the building is 291.6 m high, and a mast structure with a height of 54.37 m is standing at the top of the building. From 13:00 to 14:00 on May 18, 2021, the occupants in Saige Plaza Building reported that the building experienced significant vibration and strong tremors. On May 19 and 20, the building as well as the masts vibrated again. The monitoring sensors deployed in the building also captured significant vibration signals during different periods of time on May 20 (Yang et al., 2021; Hu et al., 2022).

As shown in Fig. 1c, a surveillance camera installed on the roof of Saige Plaza Building captured vibration of the twin masts. Based on the vibration video from May 15 to May 22, we investigated the mast vibration characteristics by a deep learning augmented vision-based method (DAVIM) (Huang et al., 2021). A test has been carried out to verify the accuracy of DAVIM in outdoor situations. Then the vibration characteristics and mechanism of the masts are investigated by analysing the surveillance video data using DAVIM.

(a) Main building (b) Roof masts (c) Position of surveillance camera and roof masts

Figure 1. Saige Plaza Building and its roof plan.

2. DAVIM METHOD

2.1. Method

DAVIM is a highly robust displacement measurement algorithm, mainly focusing on solving the problem of poor image quality. CNN is used for object tracking to deal with complex movements of object such as rigid-body rotation and size change. GAN is also used to restore images heavily corrupted by harsh environment (Huang et al., 2021). However, DAVIM defaults to having artificial object attached to the structure beforehand, and camera view is appropriate. But in general outdoor situations, the arrangement of camera and objects may not be the most ideal.

2.2. DAVIM in undesirable situations

An indoor experiment has been designed to investigate the accuracy of DAVIM in unfavourable situations. As shown in Fig. 2, the motion of the swing motor would be measured simultaneously by camera and LDS. The angle α was changed to study the effect of camera tilt. The paper marker and bolt were selected as artificial and natural objects respectively to study the effect of object type. Fig. 4 shows the measurement error of DAVIM compared to LDS. The error with artificial object is smaller than that without artificial object, but not much different. Errors were all within 1 pixel for camera tilt angles from 0 to 20 °. The tilt angle of surveillance camera at the rooftop of the Saige Plaza Building is about 20 °. The scale factor at mast top is about 40 mm/pixel, then it can be inferred that the error of DAVIM in measuring displacements of the masts is about 40 mm.

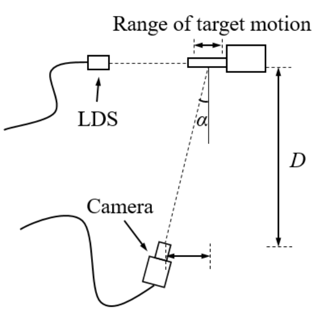


Figure 2. Test arrangement.

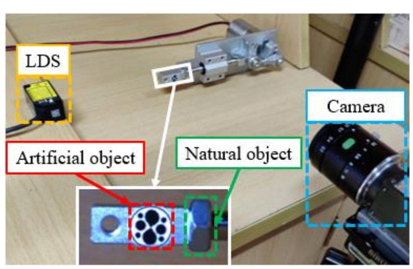


Figure 3. Test devices.

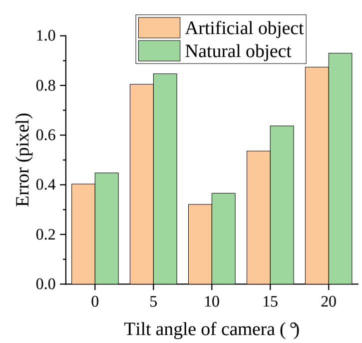


Figure 4. Measurement error of DAVIM.

3. VIBRATION IDENTIFICATION FOR ROOF MASTS OF THE SAIGE PLAZA BUILDING

3.1. Vibration video records for roof masts of Saige Plaza

A typical image in the video is shown in Fig. 5, both the north and south masts are captured in the frame. By browsing full-day surveillance video records from May 15 to May 22, the vibrations within video are roughly divided into two types (Fig. 6). Type A is the swing of the cantilever parts along the opposite direction. Type B is the overall movement of the masts at a high frequency. Then DAVIM was used to further investigate these two types of vibrations. Four recognizable regions at top and bottom of the masts were selected as objects (Fig. 5). Assuming that the bottoms of masts are stationary for correcting the top displacements.

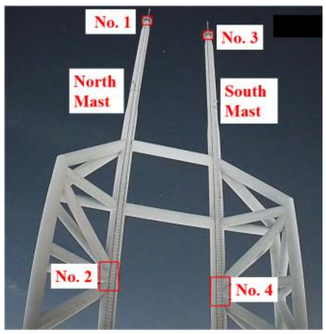


Figure 5. Masts in the video.

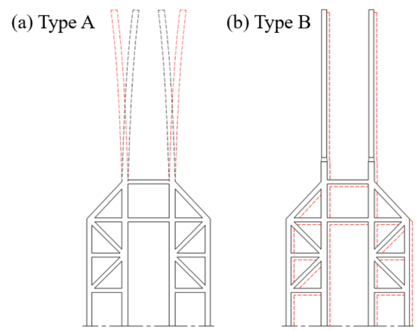


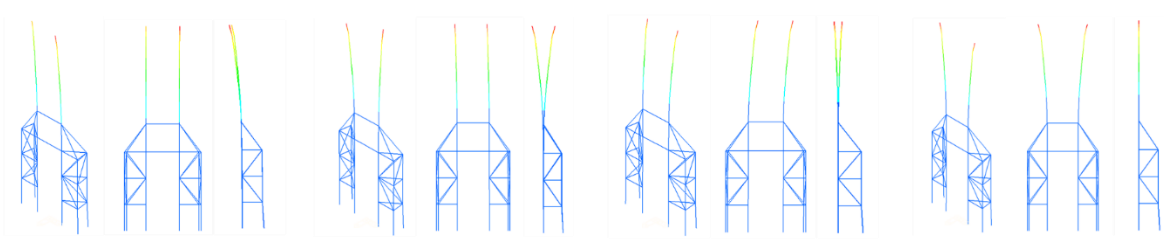
Figure 6. Two types of mast vibration.

3.2. Camera self-vibration

It was observed that Type B vibration occurred daily from May 15 to May 22, which might be caused by camera self-vibration. By analysing the time series and power spectrum of type B vibration, founding that two masts vibrated at same frequency about 7.62Hz. This vibration frequency was further confirmed by the video data collected when artificially shaking the camera. To reduce the effect of camera self-vibration, the high-frequency component (7.62Hz) of displacement data was removed by low-pass filtering in the subsequent processing.

3.3. Mast vibration characteristics

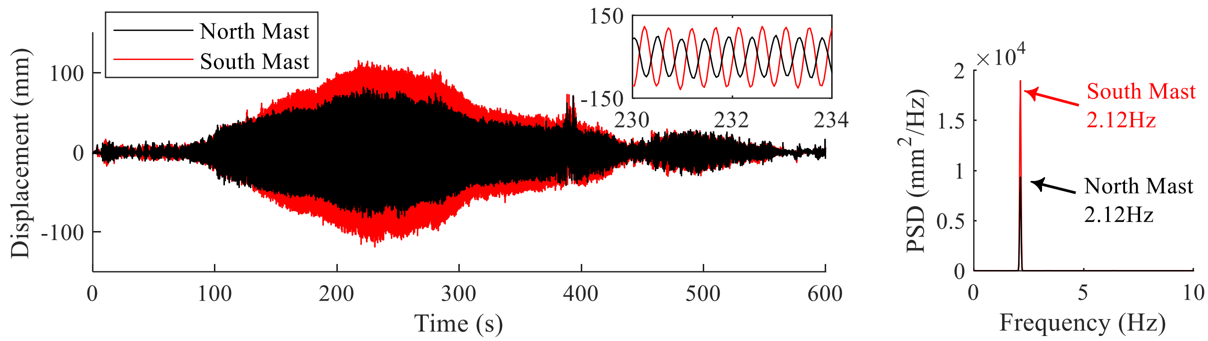
Type A vibration patterns had been recorded several times at noon on May 16, 18, 19 and 20. It mainly involves the swinging of the mast tip, which might be explained by vortex-induced vibration of the cantilever mast tube. Based on the finite element analysis of mast structure, four vibration modes with their frequencies are shown in Fig. 7. Given the 4th self-vibration frequency of 2.12Hz, the mast diameter of 1.1m, and the Strouhal number of 0.2, the critical wind speed of mast vortex-induced vibration is calculated (Sarpkaya, 2004; Huang et al., 2021) to be 11.7 m/s.



(a) The 1st mode (1.67Hz) (b) The 2nd mode (1.85Hz) (c) The 3rd mode (2.04Hz) (d) The 4th mode (2.12Hz)

Figure 7. Vibration modes of the mast structure.

Fig. 8 shows a 10-minute vibration at noon on May 18. The masts exhibit a maximum amplitude of more than 100 mm, and two masts vibrated in anti-phase. The displacement amplitude of south mast is larger than the north one, inferring the south mast has more serious rust. The vibration frequency of both masts is 2.12Hz, which is equal to the 4th vibration frequency of the mast structure. Considering the wind conditions at noon on May 18, the masts might experience a significant 4th order vortex-induced vibration with two masts in-plane synchronous vibrating along opposite directions.



(a) Displacements time series (b) PSD of two masts

Figure 8. A typical vortex-induced vibration of masts at noon on May 18.

4. CONCLUSION

We apply the deep learning augmented vision-based method (DAVIM) to identify the dynamic displacements of roof masts located at the top of Saige Plaza Building, Shenzhen. Firstly, an indoor test has been carried out and the results demonstrate that DAVIM is applicable for displacement measurement in harsh outdoor environment. Two types of mast vibration are identified by the DAVIM based on vibration video data. The overall vibration of masts (Type B) around 7.62Hz is attributed to the camera self-vibration. The vibrations of cantilever parts of twin masts (Type A) are identified as vortex-induced vibration. It was found that the masts experience the 4^{th} mode vortex-induced vibration of 2.12Hz at most of the time and the vibration amplitude of south mast is larger than the north mast.

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