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VIDEO CAMERA-BASED VIBRATION MEASUREMENT FOR CONDITION ASSESSMENT OF CIVIL INFRASTRUCTURE

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Non-contact, computer vision, vibration analysis, motion magnification

INTRODUCTION

Remote non-contact measurement methods can have many advantages over traditional non-destructive testing (NDT) and structural health monitoring (SHM) methods of condition assessment. Cameras offer the opportunity to easily make measurements remotely as they are relatively inexpensive and can be set up quickly. Traditional methods of measurement typically involve contact sensors or close proximity which can be time consuming to inspect a large structure, but they also collect higher precision data; cameras can collect spatially dense data, as every pixel represents a time series, at the expense of lower precision. Recent work has used cameras and computer vision techniques to qualitatively and quantitatively analyze the motion of objects. Davis *et al.* (2014) were able to recover sound i.e. a time series signal from an object using video only, and in related work, detect changes in the material properties of objects (Davis *et al.* 2015). Motion magnification is a technique that can amplify small motions in videos, which can be used to qualitatively see an object’s mode shapes (Wadhwa *et al.* 2013). Using a processing method inspired by motion magnification and also used in this paper, a camera was used for modal analysis of simple structures in a laboratory setting (Chen *et al.* 2015a; Chen *et al.* 2015b).

The purpose of this paper is to present a method for using a video camera to make ambient vibration measurements that can be used for the condition assessment of civil infrastructure. One such piece of infrastructure is a tower used for mounting antennas to buildings, occasionally referred to as a crow’s nest. Being on the roof of a building, they’re exposed to high winds and rain and subject to damage from corrosion. As a proof of concept, a measurement was made from a distance of over 580 feet of a crow’s nest, which resides on top of the Green Building on the campus of the Massachusetts Institute of Technology (MIT). This measurement of its resonant frequency is verified by a close range measurement made with a laser vibrometer. Using this methodology a structure can be remotely monitored over time with a camera by tracking any drastic changes in its ambient displacement vibration signal that might be indicative of damage in the structure. The ease of instrumentation and inexpensive equipment makes this a viable option for many different types of civil infrastructure.

Calculating Displacement from Videos

The process for extracting a displacement signal from a video, inspired by motion magnification (Wadhwa *et al.* 2013) is outlined as follows. Individual images in the video are transformed into a local spatial amplitude and phase representation using local steerable filters (Freeman and Adelson 1991). If illumination remains unchanged, we can obtain the displacement signal by analyzing how constant contours of the local phase move in time (Fleet and Jepson 1990; Gautama and Van Hulle 2002). A full description of the procedure is contained in the Chen *et al.* 2015a and 2015b papers.

RESULTS AND DISCUSSION

Experimental Setup

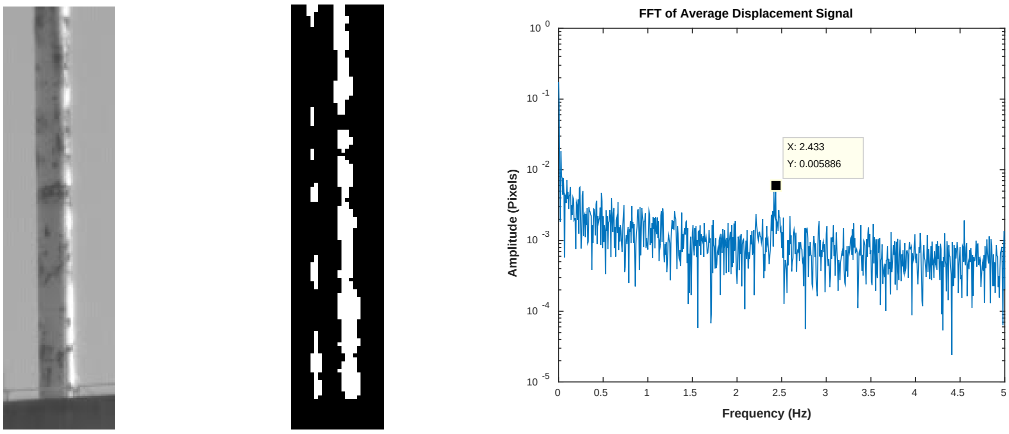
The video measurement of the Green Building was made from a distance of approximately 580 feet (by land) on a terrace of the Stata Center, another building at MIT as shown in Figure 1(a). A picture of the experimental setup and the view from the measurement location is shown in Figure 1(b). A Point Grey Grasshopper3 camera was used to record a 150 second long video at 10 frames per second (fps) and a resolution of 1200 × 1920, where 1 pixel corresponds to about 3.65 cm at the depth of the structure, a magnification factor of 1:3170. A screenshot from the recorded video is shown in Figure 1(c) showing the Green Building filling most of the frame of the video, with the crow's nest visible as the long thin structure on the roof of the building.

(a) Satellite view (b) View from measurement location (c) Screenshot from video

Figure 1 Experimental setup for measurement of MIT's Green Building, crow's nest seen at top

Results

The video was processed using the previously described procedure. Even though the building's motion was too subtle to recover from this distance, vibrations of the crow's nest were strong enough to generate a recoverable signal. Shown in Figure 2(a) is the cropped video of the crow's nest, with Figure 2(b) showing high contrast pixels with displacements extracted from the video. These displacements were averaged to obtain a single signal for the structure, and an FFT was taken to determine the frequency spectrum shown in Figure 2(c). In the frequency spectrum there is a resonant peak at 2.433 Hz which suggests that the crow's nest atop the building has a resonant mode at that frequency. The amplitude of the resonant peak from the crow's nest works out to be 0.21 mm. The noise floor for the measurement is approximately 0.07 mm, which gives a signal to noise ratio of 3. For these measurement parameters, any structural motion above the noise floor would be measureable. Improvements can be made by using a more telephoto zoom lens in addition to a higher resolution camera.

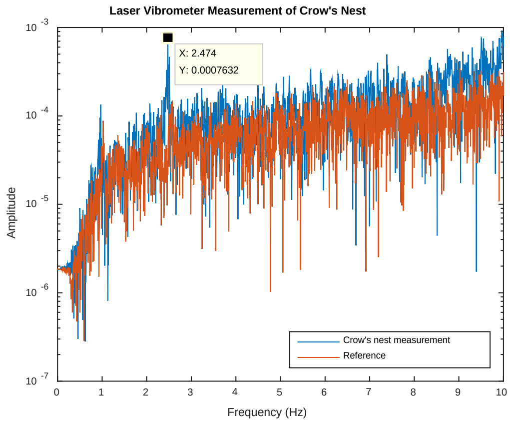


(a) Cropped video screenshot (b) Pixel mask (c) FFT of average displacement signal

Figure 2 Results from camera measurement of the Green Building crow's nest

Verification

As verification for the resonant frequency of the crow's nest measured by the camera, a laser vibrometer was used to measure the frequency response during a day with similar weather conditions. Figure 3(a) shows the measurement setup on the roof of the Green Building, measuring the crow's nest vibrations from close range. A measurement was also made of the ground next to the crow's nest as a reference so that any vibrations of the tripod itself could be discounted. The laser vibrometer measurement is shown in Figure 3(b) with the crow's nest signal shown in blue and the reference signal in red. Two potential resonant peaks are seen in the crow's nest measurement, however the peak at around 1 Hz is also seen in the reference measurement and thus not a resonance of the crow's nest. The other peak occurs at 2.474 Hz which is similar to the 2.433 Hz measured by the camera; this lends credibility to the camera measurement.



(a) Laser vibrometer measurement setup (b) Measurement result with static reference for comparison

Figure 3 Laser vibrometer verification of MIT Green Building crow's nest resonant frequency

CONCLUSIONS

A camera-based measurement methodology for vibration analysis of civil infrastructure was demonstrated by measuring the ambient vibration response of the crow's nest atop MIT's Green Building from a distance of over 580 feet. The resonant frequency measured by the camera agreed with the frequency determined from a laser vibrometer measurement made from close range. With this measurement, the motion of structures with displacements greater than 0.07 mm could be detected. Further work will lower this noise floor limit so that more structures can be monitored with remote camera-based vibration measurements.

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