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Extracting modal parameters of a cable on shaky motion pictures

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ABSTRACT

A set of modal parameters of a cable are extracted from a motion picture captured by a digital camera operated with shaking hands. It is difficult to identify the center of the targets attached to the cable surface from the blurred motion image of the cable, because of the high-speed motion of the cable, low sampling frequency of the camera, and the effect of shaking hands on the motion pictures. This paper proposes a multi-template matching algorithm to solve these difficulties. In addition, a sensitivity-based system identification algorithm is proposed for extracting the natural frequencies and the damping ratios from ambient cable vibration data. Three sets of vibration tests are performed to examine the validity of the proposed algorithms. The results show that the proposed approach of using these two algorithms is fairly feasible for extracting modal parameters from severely blurred motion pictures.

1. Introduction

The construction of cable-stayed bridges has emerged as a recent trend. The safety of the cables on such bridges is directly related to the overall safety of the bridge system, and therefore, various on-line monitoring systems [1–7] for cables have been developed and operated. The extraction of modal parameters is considered to be an important step for examining the safety of cables.

To measure the dynamic response of a cable, typically, a low-frequency accelerometer is attached to the cable surface. However, the process of installing such accelerometers is quite cumbersome for several-hundred-meter cables. Noncontact sensors such as a laser Doppler vibrometer [2] or motion-picture cameras [3] can be useful tools for solving such problems. A method involving the use of a laser Doppler vibrometer has a relatively high accuracy; however, it is quite expensive comparing to the other measurement technique. Meanwhile, a vision-based technique that uses a camera or a camcorder is very attractive because of its low-cost.

However, the vision-based technique suffers from the drawbacks of low accuracy because of the following two problems. First, a blurred image is unfeasible for a moving target [8]. In this case, the automatic identification of the exact target positions is very difficult. Second, modal parameters should be determined from output-only data. This leads to low accuracy when traditional peak-picking techniques [9] are used to extract modal parameters.

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With the aim of resolving the two abovementioned problems in the vision-based technique, this study proposes a new approach for extracting the modal parameters of a cable from a set of blurred images. This approach can be used to resolve the blurred-image problem by implementing the multi-template matching technique [10] and the system identification technique [11]. In addition, we adopt the fundamental concept of an output-only modal parameter technique [12,13] to improve extraction accuracy.

2. Theory

Consider a general portable digital camera that can capture 30 frames per second, while the feasible frequency range of the proposed technique only relies on the maximum shutter speed of a camera or camcorder device. If a motion picture of a cross-shaped target attached to a vibrating cable is captured, the typical output is blurred images, as shown in Fig. 1. The afterimage effect occurs because the target moves faster than the time for which the shutter of the camera is exposed to light. Fig. 1 shows the same moving target extracted from a motion picture. The afterimage effect is very severe in Fig. 1c and d. The center of the cross-shaped target is hardly identifiable. Whereas Fig. 1a and b has the slight afterimage effect, the identification of a unique center position of the target is still not easy.

This afterimage effect hinders the correct identification of the target position. The multi-template matching technique [10] has drawn special attention for resolving this problem. This technique involves registering the multiple blurred sub-images shown in Fig. 1 as templates and searching in an overall original image to find the best-matching region.

Consider an $m \times n$ original image $f(x,y)$, shown in Fig. 2. The multi-template matching technique is used to locate a region that is most similar to a previously defined $p \times q$ sub-image $w(x,y)$.

To find the best-matching region, cross-correlation between the sub-images and the original image is commonly used. The ith cross-correlation $\gamma_i(u,v)$ in the original image $f(x,y)$ can be obtained by

$$\gamma_i(u,v) = \frac{\sum_{x,y}[f(x,y)-\overline{f}_{u,v}][w_i(x-u,y-v)-\overline{w}_i]}{\sqrt{\sum_{x,y}[f(x,y)-\overline{f}_{u,v}]^2 \sum_{z,y}[w_i(x-u,y-v)-\overline{w}_i]^2}} \tag{1}$$

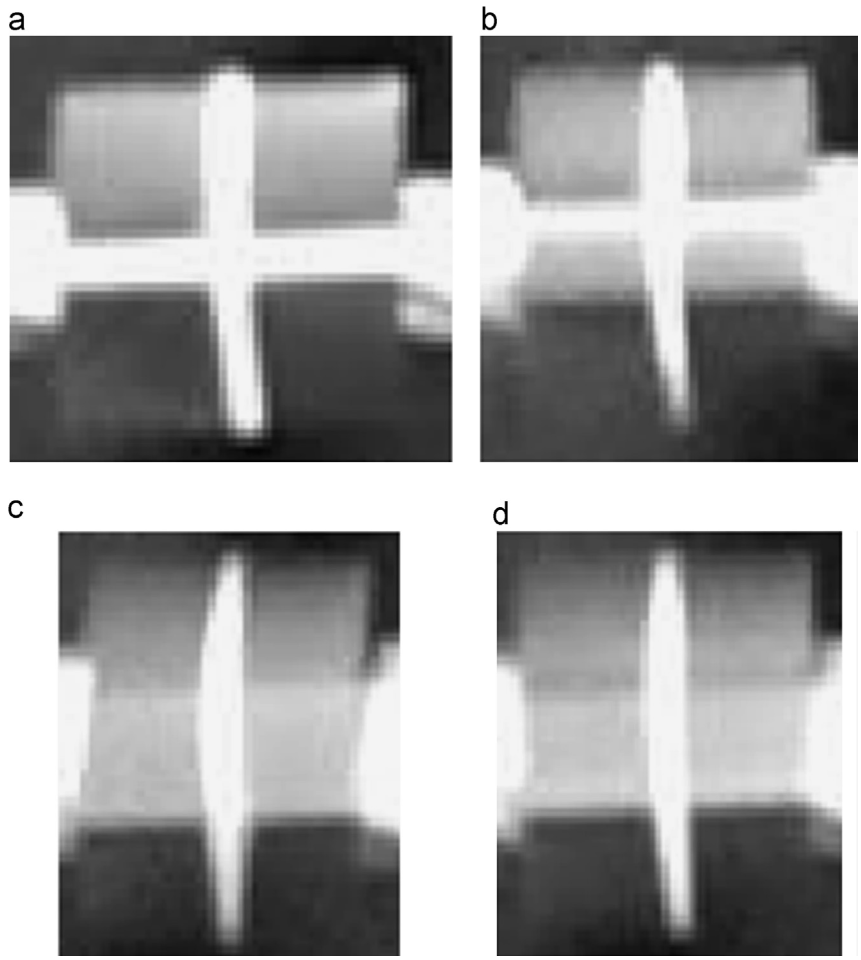

Fig. 1. Blurred cross target images.