The 2018 Structures Congress (Structures18)
Songdo Convensia, Incheon, Korea, August 27 - 31, 2018

Tension estimation of a stay cable using image processing technique

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ABSTRACT

Stay cable is a very important element in a cable-stayed bridge because cables support the bridge deck. The best way to identify the state of the cable is to estimate the tension. In general, acceleration data was used to estimate the cable tension, but it is difficult to install the sensor. In this paper, the cable tension estimation method using UAV is proposed. The displacement can be extracted from the vibration image of the cable. Then, the mode of cable was found by modal analysis to estimate the tension.

1. INTRODUCTION

In cable-stayed bridges, the stay cable is a very important component because it supports most of the load acting on the bridge. Therefore, it is necessary to continuously monitor the dynamic characteristics of the cable. Cable tension has been monitored because it reflects the dynamic characteristics.

The tension of the cable can be measured directly by using sensors such as load cell or an optical fiber, but it is difficult to install and maintain. (Yun 1999) Therefore, a method of estimating tension from the vibration data has been used. (Shimada 1995, Kim 2002, Jung 2011, Cho 2010) However, this method is costly and difficult to manage since a number of sensors must be installed on the cable for vibration measurement. In addition, special sensors such as ultrasonic (Toh 2015) and magnetic sensors are used, or non-contact sensors such as laser displacement and vision based sensors (Kim 2017, Zhao 2017) are used. The vision sensor based system is simple and can measure vibration of cable which is difficult to access. However, the

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conventional image measurement system may cause an error due to shaking by the wind.

In this paper, cable tension was estimated by using vision displacement measurement method. To obtain the image of cable vibration, unmanned aerial vehicle (UAV) was used. Therefore, the proposed system can estimate the tension more rapidly than the conventional image based tension estimation method. In addition, the vibration of the vision sensor system can be corrected using the motion values of UAV to increase accuracy. To validate performance of the proposed method, lab-scaled test was conducted, and the cable tension can be estimated.

2. CABLE TENSION ESTIMATION

The vibration method is most often used to estimate the cable tension when sensors to measure tension isn't install at the construction stage of the cable. The vibration method generally conducts the following procedure. First, cable vibration due to the ambient vibration and the exciter is measured through the sensors such as accelerometer or displacement sensor. Then, the mode of the cable is extracted through frequency analysis.

2.1 Vision Sensor System based on UAV

In this study, the vibration response of cable was measured using vision camera mounted on UAV. Unlike the existing system, it does not require experimental setup and additional equipment. Therefore, proposed approach is highly portable and simple. In experimental test, a commercial UAV (Phantom 4 Pro, DJI) with 1-inch 20-Megapixel CMOS vision sensor is used.

Fig. 1 Commercial UAV (Phantom 4 Pro, DJI)

2.2 Experimental Setup

Fig. 2 shows the experimental setup. The length of the cable used in the experiment is 11.8 m, mass per unit length is 4.229 kg/m, and the diameter is 28.6 mm.

The cable is insulated by using a high density poly-ethylene (HDPE). 4 x 4 matrix color marker is considered for vision based displacement estimation, and it is attached on the mid-point of cable.

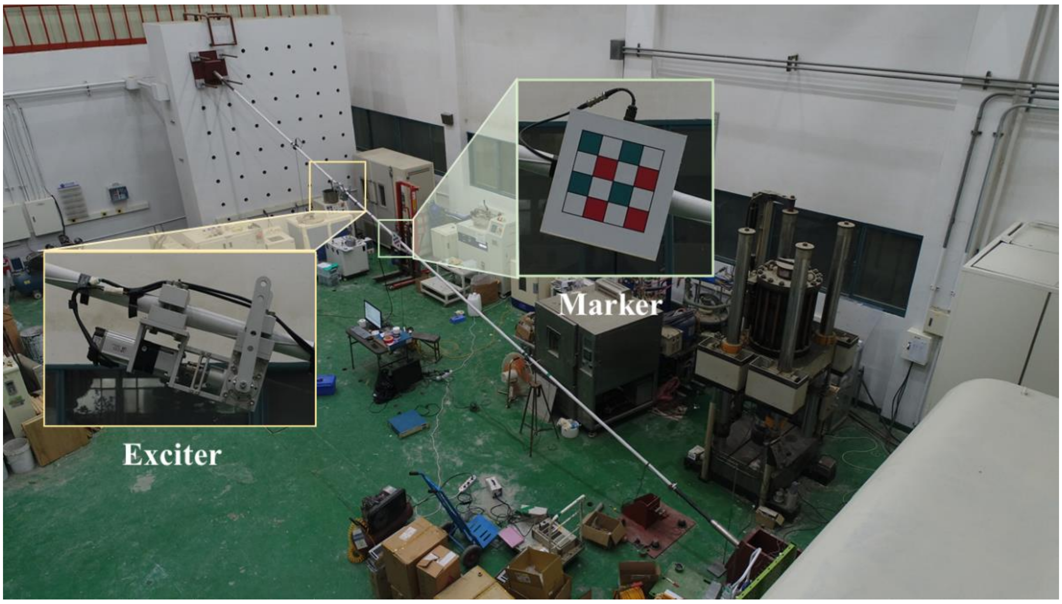

Fig. 2 Experimental Setup

The cable is insulated by using a high density poly-ethylene (HDPE). 4 x 4 matrix color marker is considered for vision based displacement estimation, and designed marker with accelerometer is attached on the mid-point of cable. In addition, an exciter was installed for the vibration of the cable. Experiments were carried out by measuring the response of the cable under free vibration condition after force vibration at the resonant frequency.

2.3 Result of cable tension estimation

In this study, the procedure for estimating cable tension using video is as follows. First, dynamic frames of the marker are acquired using the vision camera mounted on the UAV, and then images converted into displacement. Second, PSD based displacement response is obtained through the FFT. Next, the resonance frequency of the cable is found through the peak-picking method. Finally, the tension of the cable is estimated using Eq. (1). (Jung 2011)

$$\left[\frac{f_n(1-\varsigma_n^2)}{n}\right] = \frac{g}{4wl}\left[1+\frac{2\lambda^2}{\pi^4}\frac{[1-(-1)^n]^2}{n^4}\right]T + g\frac{EI\pi^2}{4wl^4}n^2 = a + bn^2 \quad (1)$$

where, f_n is the nth natural frequency, ς_n is the nth damping ratio, T is the tension, g is the acceleration of gravity, w is the weight per unit length, l is the effective length,

λ^2 is the coefficient related with sag, E is the Young's modulus and I is the moment of inertia of the cable.

The tension of the cable used in the experiment was estimated to be 50.3 kN. These results are consistent with the tension value considered in the design and construction stage.

3. CONCLUSIONS

In this study, the vibration method using UAV was used to estimate the tension of stay cable. In the experiment, length of cable is 11.8 m, and commercial UAV with 4 x 4 color marker was used. As a result, proposed method can estimate the tension of cable. Therefore, the performance of the cable tension estimation method using UAV is verified.

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Financial support from Construction Technology Research Program funded by Ministry of Land, Infrastructure and Transport (MOLIT) of Korean government (18SCIP-C1167873-03).

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