DYNAMIC BEHAVIOR ANALYSIS OF BRIDGES BY VIDEO PROCESSING

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動画像処理による橋梁の動的挙動分析

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近年画像計測は大きな注目と期待が寄せられている．橋梁の動的挙動を，ターゲットを設置することなしに動画撮影のみから取得する試みを行った．本研究では，従来静止画に広く用いられてきた位相限定相関法に着目し，これを動画像に対して適用したところ，物体の移動の追跡ならびに振動数を把握することができた．またこれを実橋梁に対し適用することで，たわみ挙動ならびに固有振動数を取得可能であることを確認した．また，橋梁本体部のみならず橋梁ケーブルの振動に対しても，固有振動数を特定するために動画像処理を適用できることを示した．

Keywords : *video processing, displacement, frequency, bridge, deformation*

1. INTRODUCTION

It is important to figure out bridge dynamic behavior such as deflection and vibration in terms of safety and environmental view. When we observe bridge vibration and get mode shapes, we usually use accelerometer. Using accelerometers enable us to detect microscopical vibration. However, accelerometers must be installed directly on the object that wants to be measured, so its process requires a lot of work. Moreover, when the object is located at height, it may be dangerous.

In recent years, image measurement methods are attracting a lot of attention to figure out dynamic behavior. With these methods, we need not to install accelerometers or other devices directly on target objects and we can obtain displacement at multiple points from a single image, so measurement tasks will become more efficient and easier.

There has been a lot of study on image measurement. Morimoto[1] used the sampling moire method for image measurement, and Tsuda[2] measured the deflection of bridges using this method. Although this method can obtain deflection with good accuracy, moire pattern markers or other periodic patterns must be installed on the side of bridges to make measurement. In order for image measurement to be versatile and practical, it must be without markers as there are bridges that are difficult to be installed markers.

Thus, the objective of this research is the assessment of the image measurement method applied to bridge measurement without marker. Also, we can get frequency information from time history displacement. Not only bridge deflection but also vibration characteristics are set as the target of video processing.

In addition, bridge cables are also the objects of interest. Shinke[3] proposed vibration method to estimate the tension from the natural frequency of the cable. Image measurement has the potential to be used for figuring out not only deformation but also the condition of components such as tension. In this research, measurement of bridge cables is set as the additional research object.

2. DATA PROCESSING METHOD

(1) Phase Only Correlation method

It is supposed that we have the two-dimensional source image $f_1(x, y)$ and the moved image $f_2(x, y)$. When the two-dimensional Fourier transform of these images are denoted as F_1 and F_2 respectively, they can be expressed as follows:

$$F_1(m,n) = A_1(m,n)\exp\big(i\theta_1(m,n)\big) \quad (1)$$
$$F_2(m,n) = A_2(m,n)\exp\big(i\theta_2(m,n)\big) \quad (2)$$

Their normalized cross power spectrum R provides the difference of phase components:

$$R(m,n) = \frac{F_1\overline{F_2}}{|F_1\overline{F_2}|} = \exp\big(i(\theta_1 - \theta_2)\big) \quad (3)$$

Phase Only Correlation function r is obtained by inverse Fourier transform of R:

$$r(x,y) = \mathcal{F}^{-1}R \quad (4)$$

The maximum value of r indicates correlation degree of these images and its position shows movement between these images. However, since it is necessary to obtain the displacement with sub-pixel accuracy, fitting to the model function was used to find the maximum value.

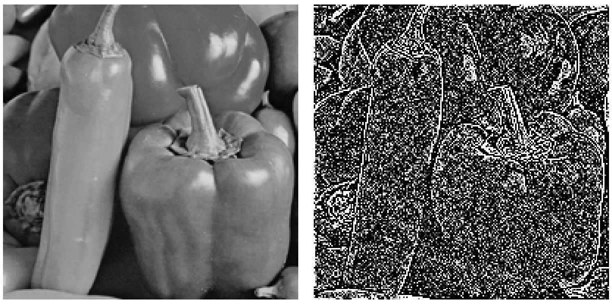

Fig 1 contour information of images from phase components

POC uses only phase components, which have contour information. Conventional image correlation methods, such as motion capture and Digital Image Correlation (DIC), directly use luminance values. For that reason, these methods are not suitable for long time and outdoor measurements, which are susceptible to change of sunlight. On the other hand, since POC uses only contour information, there is no problem even if the brightness of analysis areas changes during measurement, making it suitable for outdoor measurement.

(2) Applying POC to video

POC is originally applied to not only still images but also video recordings by considering flames as images. Movement at each time is obtained by calculating POC between the flame at that time and that at first time as reference point.

(3) Converting movement to actual displacement

Since movement obtained using POC is expressed in pixels, it needs to be converted to actual dimension. To convert the value, simple camera projection model **Fig 2** shows is used.

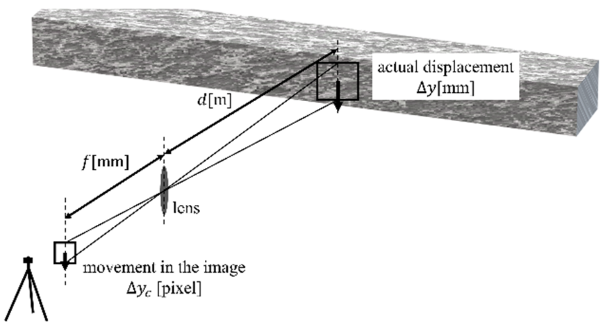

Fig 2 simple camera projection model

Considering the model **Fig 2**, when d is much longer than f, the actual displacement Δy[mm] can be calculated from movement in the image Δy_c[pixel] by the following equation:

$$\Delta y = \frac{1000ad}{fN}\Delta y_c = k\Delta y_c \tag{5}$$

where N[pixel] is the number of active pixels, a[mm] is the size of camera sensor, f[mm] is the lens focal length, d[m] is the distance from the camera to the object. k is named the correction factor for scale conversion.

3. PRELIMINARY MEASUREMENT

(1) Settings

2 types of steel plates, rusted steel plate on the top and not rusted steel plate on the bottom, imitated bridge girder surfaces were moved with experiment machine, which **Fig 3** shows. Synthetic waves were input to the shaker and the scene was recorded in 4K 30fps by a commercial video camera, SONY α7C. Base isolation pads were used under the support to reduce transmission of the machine vibration to the camera.

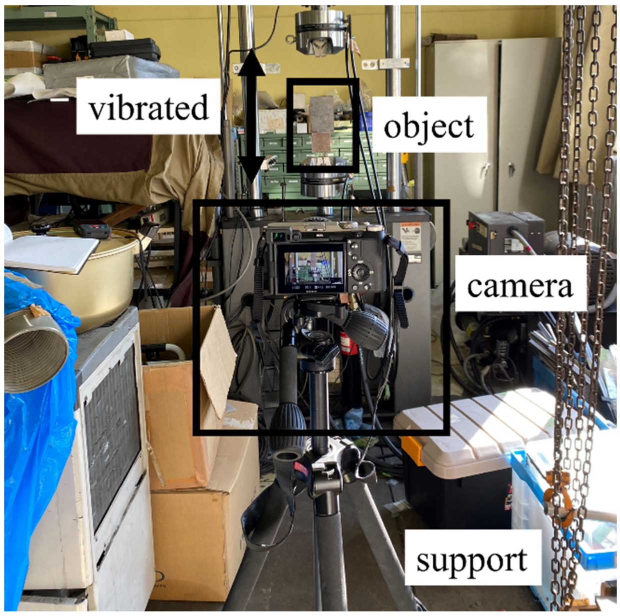

Fig 3 the setting of the sample measurement

(2) Result and Discussion

Fig 4 shows the comparison of the displacement at machine by LVDT and each plate by video processing. The waveforms by video processing were similar to that by LVDT, but the amplitudes were larger. Since the waveforms were obtained properly, the cause of the errors would be scale conversion.

In addition, although video processing was performed for each of two steel plates, but there was no significant difference in both displacement and frequency obtained. Therefore, no change in displacement and frequency result due to difference in surface patterns was observed.

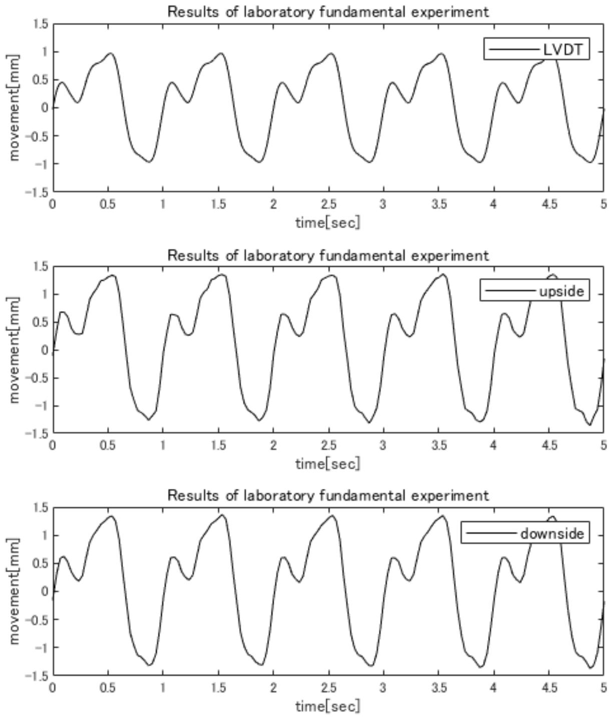

Fig 4 results of the sample measurement

4. MEASUREMENT OF BRIDGE

(1) Location and settings

Measurement at the single span RC girder bridge on the Seisho Bypass was conducted. The bridge video was recorded in 4K 30fps about 7 meters in front when heavy vehicles were passing. To compare the result, a laser displacement sensor was installed under the bridge and displacement was recorded simultaneously. The recording setting is shown in **Fig 5**.

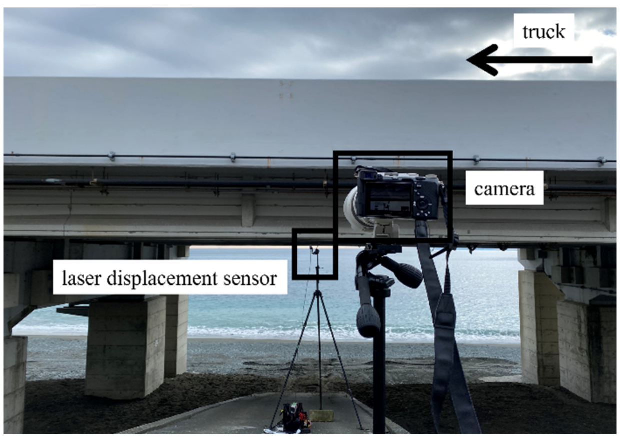

Fig 5 the setting of the bridge measurement

(2) Result and Discussion

Fig 6 shows the comparison of measurement results obtained from laser displacement sensor and video processing.

The waveform by video was also similar to that by laser displacement sensor, but the amplitude was deviated. The movement from video was smaller than that from other measurement method unlike sample video that showed the opposite result. When other vehicles passed by, the degree of error was about the same and since errors were also observed in the first experiment, it is thought that there was a problem in the process of conversion to real scale.

In terms of the frequency domain, spectrum from both laser displacement sensor and video contained the 7.3Hz peak, which showed frequency was able to be detected accurately. However, the power spectrum from video also contained other peaks which that from laser displacement sensor did not. Therefore, there is room for improvement to ensure better accuracy and more reliable results.

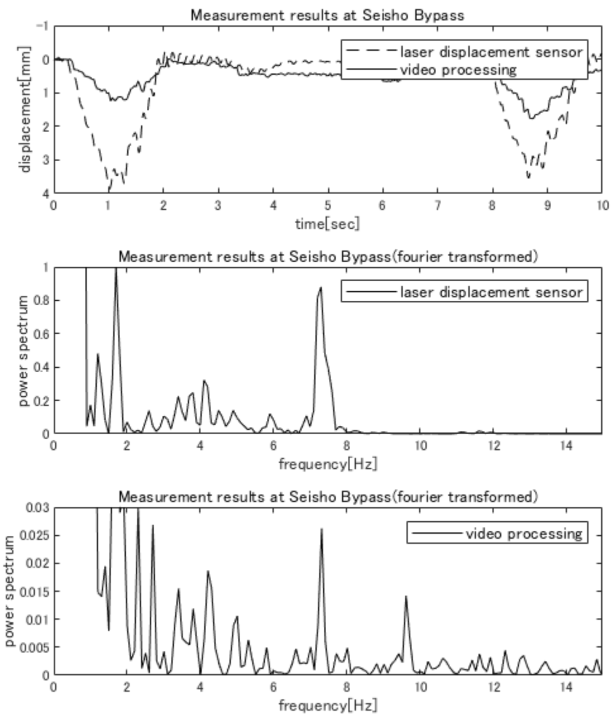

Fig 6 results of the bridge measurement

5. MEASUREMENT OF CABLE

(1) Location and settings

The cable vibration was measured using the wooden pedestrian bridge in the campus of Tokyo Institute of Technology. The bridge is equipped with cables. One of the cables was vibrated by hand hitting and the scene was recorded in HD 120fps under the bridge. The recording setting is shown in **Fig 7**.

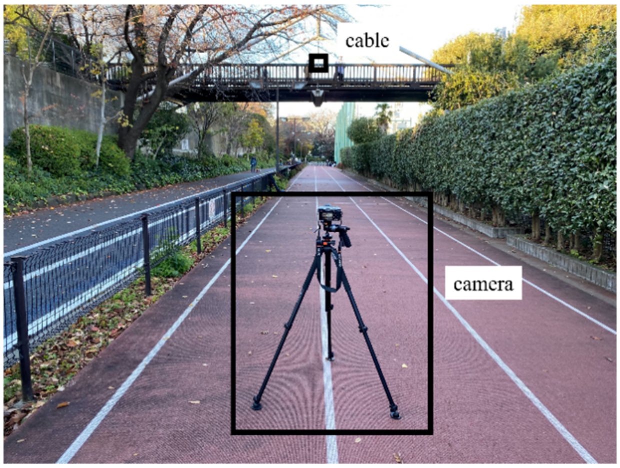

Fig 7 the setting of the cable measurement

(2) Result and Discussion

Fig 8 shows the results of cable measurement. The result from video processing showed a spectral peak at 22.6Hz, same as that from the accelerometer. Based on the results of videos taken from various distances, it was possible to obtain the natural frequency of the cable by video processing properly within about 20 meters.

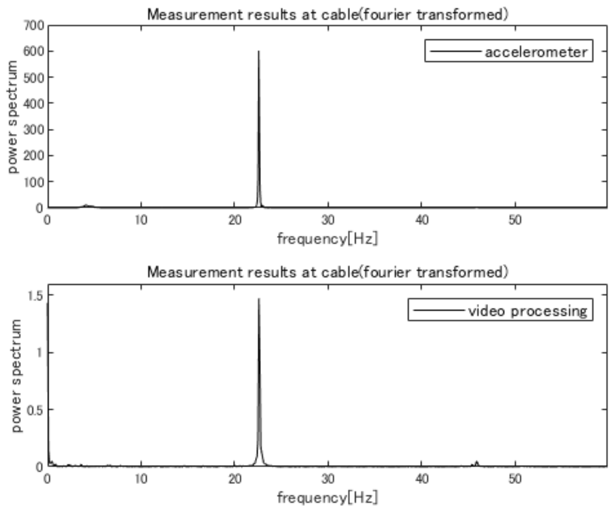

Fig 8 results of the cable measurement

6. VISUALIZING DEFORMATION

Advantages of image measurement are not only the ability to acquire displacement from a distance but also the ability to obtain displacement of multiple points simultaneously at once. **Fig 9** shows bridge deformation by video processing at multiple points. As shown in the figure, an appropriate deflection shape was obtained, but in order to obtain more accurate deformation result, it is necessary to remove the distortion component of the image so that there is no difference between the center and the edge of the image.

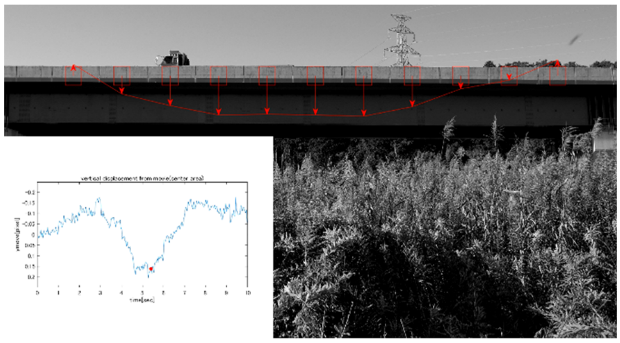

Fig 9 visualizing the deformation of bridge

7. CONCLUSIONS

The obtained knowledge is following below:

- Phase Only Correlation method, conventionally used for image measurement, is effective not only in still images but also in videos and movement can be obtained by using POC.
- The deflection waveform of the bridge can be obtained by using POC, but the amplitude is far from the true value and further verification is needed.
- The frequencies of bridge behavior and cable vibration can be obtained within a proper distance.
- The possibility of expressing the deformation behavior of bridges and other structures by taking advantage of the multipoint measurement capability of image measurement was shown.

In the future, it will be necessary to examine the cause of inability to obtain appropriate displacement values and to accumulate data by conducting more measurement on various bridges.

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