

ENVIRONMENTAL EFFECT ON VISION-BASED STRUCTURAL DYNAMIC DISPLACEMENT MONITORING

X. W. Ye^{*}, C. Z. Dong and T. Liu

Department of Civil Engineering, Zhejiang University, Hangzhou 310058, China

^{*}Email: cexwye@zju.edu.cn

ABSTRACT

Structural dynamic displacement is an important indicator of the health condition of long-span bridges. Monitoring of bridge dynamic displacement has been a critical task within the context of structural health monitoring (SHM). Traditionally, the structural displacement measurement methods are contact, wired and time-consuming. With the great progress of image processing technique and vision robot science, the vision-based monitoring systems have been developed rapidly and received a huge amount of attentions in the field of SHM. However, in the practical applications, the environmental factors will affect the operational performance of the vision-based system. In this study, a series of comparative experiments are conducted to explore the robustness of vision-based structural dynamic displacement monitoring under varying illumination conditions by use of various types of vision targets (quick response (QR) code and LED lamp). The experimental results indicate that the robustness of the vision-based system is weakened under poor illumination conditions when the QR code is used to be the vision target in comparison with the vision target of LED lamp.

KEYWORDS

Structural health monitoring, structural dynamic displacement, vision-based system, pattern matching, environmental factors.

INTRODUCTION

Civil engineering structures are prone to vibrate under the external stochastic loadings (e.g., wind, earthquake and traffic), which will result in fatigue damage and cracking in critical structural components. Monitoring of the structural dynamic responses is helpful to update structural models, build damage identification methods, and establish vibration control strategies. Structural vibration monitoring and dynamic characteristics identification have been one of the most important issue within the field of structural health monitoring (SHM) (Ni *et al.* 2010; Ni *et al.* 2012; Ye *et al.* 2012; Ye *et al.* 2013a).

The traditional dynamic displacement monitoring methods need to fix sensors on the target structure which will cause the issues of data transmission, power supply, traffic jam, etc. With the great progress of image processing technique and vision robot science, the vision-based displacement monitoring systems have been developed rapidly and received a huge amount of attentions in the field of SHM (Fukuda *et al.* 2010; Ye *et al.* 2013b; Ye *et al.* 2015). However, the vision-based system may be affected by the varying environmental factors, especially in the field measurements (Schreier and Sutton 2002; Yoneyama *et al.* 2006; Ma *et al.* 2012). In this study, a vision-based multi-point structural dynamic displacement measurement method is proposed. Comparative experiments are conducted between the vision-based measurement system and the traditional measurement system under different illumination levels with two various types of vision targets (quick response (QR) code and LED lamp).

METHODOLOGY

For a vision-based multi-point structural displacement measurement system, the algorithm of multi-point pattern matching is able to effectively locate the targets in an image by matching the predefined patterns (Ye *et al.* 2015). Figure 1 illustrates the procedure for the structural displacement measurement by using the vision-based system. First, the digital camera is fixed in front of the monitoring object and adjusted to make the monitoring target in the field of view. Then, the initial image is captured by the digital camera with the predefined targets. Patterns containing the region of the targets in the image are extracted from the initial image. Meanwhile, the initial coordinates of the centers of the patterns are confirmed. The scale ratio represents the proportional relationship of the actual distance and the pixel coordinate difference. By using the pattern matching algorithm, the process of pattern matching is performed in the succeeding images with the predesignated patterns. When the normalized correlation coefficient in correspondence with each pattern matching reaches the maximum

value, the pattern matching is completed. The best matching position is located and the best matched pixel coordinates are achieved. The pixel coordinate difference is obtained by subtracting from the initial pixel coordinate. Finally, the structural displacement of the target is obtained through multiplying the calculated pixel coordinate difference by the scale ratio.

As illustrated in Figure 1, the vision-based multi-point structural displacement measurement system consists of a high-resolution industrial charge-coupled device (CCD) camera, a zoom lens, a computer, and a Gigabit Ethernet standard LAN wire. In this system, a Prosilica GE1050 camera with a Navidar 12X zoom extender lens serves as the image acquisition equipment.

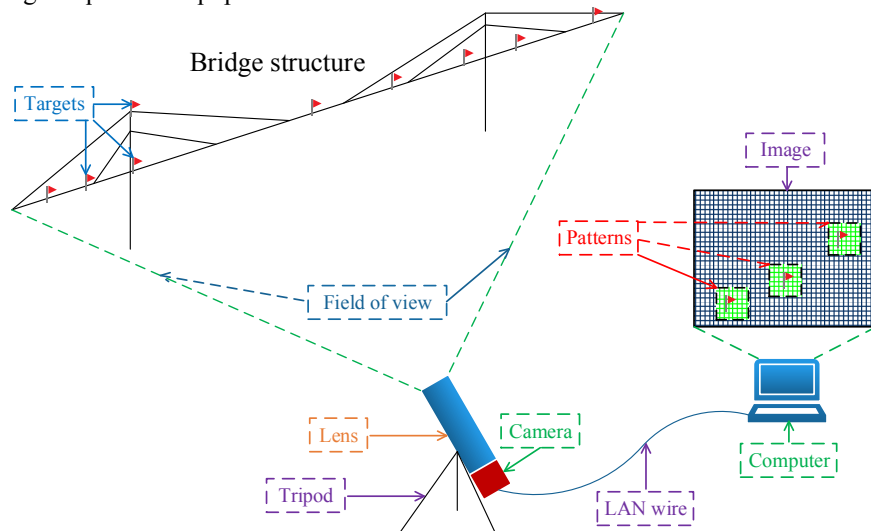


Figure 1 Vision-based system for multi-point structural displacement measurement

EXPERIMENTAL STUDY

Illumination is one of the most important environmental factors which will affect the quality of captured images and the sampling efficiency of the vision-based system. Experiments on the robustness of the vision-based multi-point structural displacement measurement system under different illumination levels are carried out. Basically, a comfortable environment with adequate illumination is desired to acquire satisfactory results of structural displacement. Under an inferior light condition, it is not easy for the digital camera to capture distinct images even though much time of exposure is taken. In this connection, the task of pattern matching will not be effectively fulfilled. In real-world applications, the vision-based system is liable to confront different kinds of illumination conditions which may make the measurement results unstable and inaccurate.

Table 1 Experiment cases with different environmental conditions

Case	Vision target	Illumination (lux)
Case 1	QR code	300
Case 2	QR code	75
Case 3	LED lamp	300
Case 4	LED lamp	75
Case 5	LED lamp	30
Case 6	LED lamp	2

As shown in Table 1, six cases including four levels of illumination (300 lux, 75 lux, 30 lux and 2 lux) and two kinds of vision targets (quick response (QR) code and LED lamp) are arranged to investigate system robustness under the different illumination conditions. As illustrated in Figure 2, the comparative experiments are conducted on a self-made shaking table on which a rigid board attached with two kinds of vision targets (quick response (QR) code and LED lamp) is fixed. Two QR codes (P1 and P2) and two LED lamps are regarded as the measurement targets for the vision-based system, as shown in Figure 2. A magnetostrictive displacement sensor (MDS) is also installed to measure the displacement of the two targets. An illumination sensor is deployed nearby the targets to record the level of illumination. The illumination condition is adjusted by switching the lamps in the room. The displacements of the targets during the vibration process of the shaking

table are simultaneously measured by the vision-based system and the MDS. The vibration frequency of the shaking table is 0.3 Hz and the sampling frequency of the two systems is 10 Hz. The distance between the digital camera and the targets is 2 m.

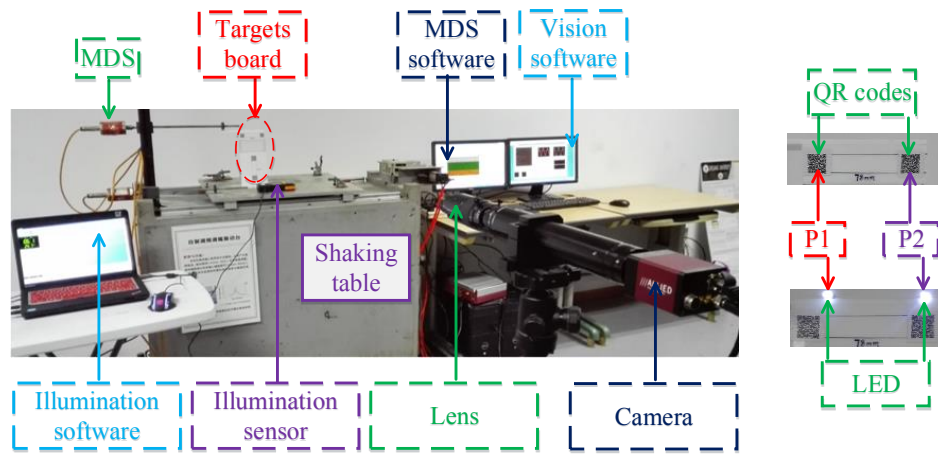


Figure 2 Experimental setup

Figures 3-8 illustrate the displacement time histories of P1 and P2 measured by the vision-based system and the MDS in the aforementioned six cases. It is seen from Figures 3-8 that in all the cases except case 2, the displacement results measured by the vision-based system are in consistent with those obtained by the MDS. However, in the case 2, when the vision targets are QR codes and the illumination is 75 lux, the vision-based system has the difficulty in accomplishing the task of pattern matching and a considerable number of spurious tones are generated. As a result, the inaccurate displacement results are obtained by the vision-based system due to the illumination effect. But in the same level of illumination (case 4), when the LED lamps are regarded as the vision targets, the displacements measured by the vision-based system are still in consistent with those obtained by the MDS. From case 1 and case 2, it is indicated that for the QR codes as the vision targets, a lower illumination will have effect on the measurement accuracy of the vision-based system and the robustness of the system is weaker under this situation. From case 2 and case 4, it is indicated that when the illumination is 75 lux, the LED lamps as the vision targets give a stronger robustness than the QR codes. When the illumination levels are brought down to 30 lux and even 2 lux in case 5 and case 6 and the LED lamps are regarded as the vision targets, the vision-based system still shows a stronger robustness as shown in Figure 7 and Figure 8.

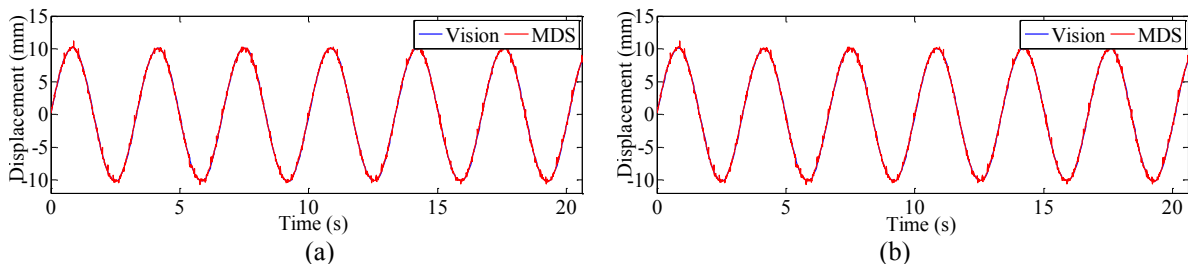


Figure 3 Displacement time histories of case 1: (a) P1, (b) P2

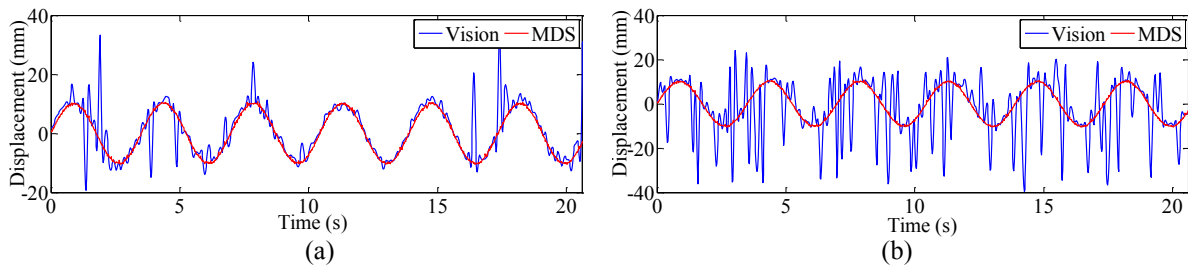


Figure 4 Displacement time histories of case 2: (a) P1, (b) P2

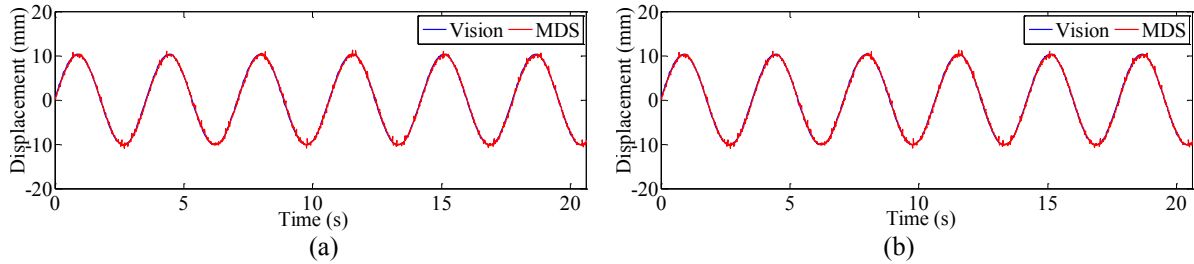


Figure 5 Displacement time histories of case 3: (a) P1, (b) P2

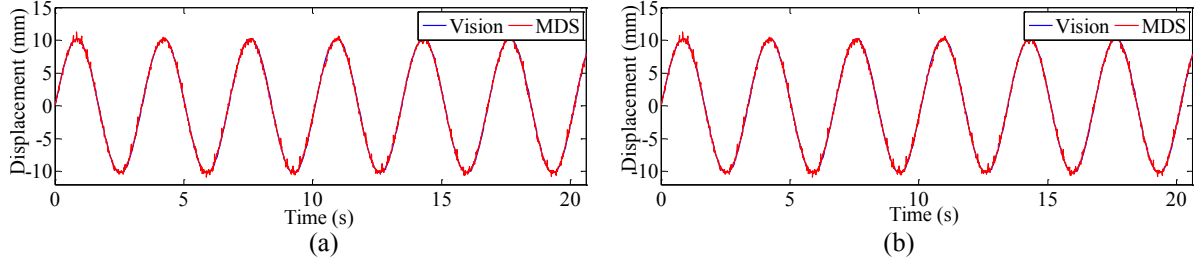


Figure 6 Displacement time histories of case 4: (a) P1, (b) P2

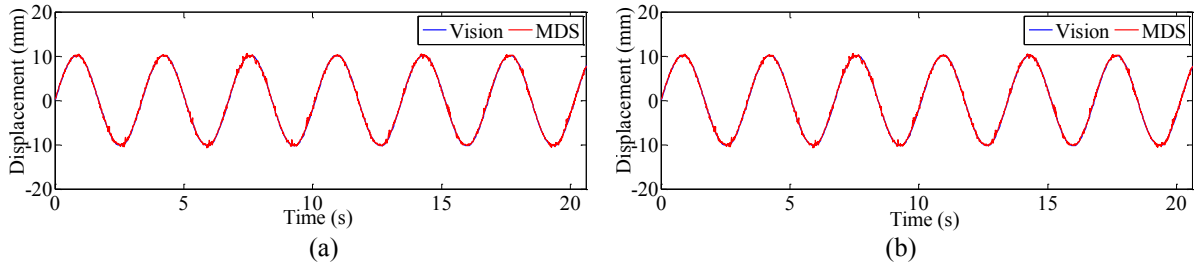


Figure 7 Displacement time histories of case 5: (a) P1, (b) P2

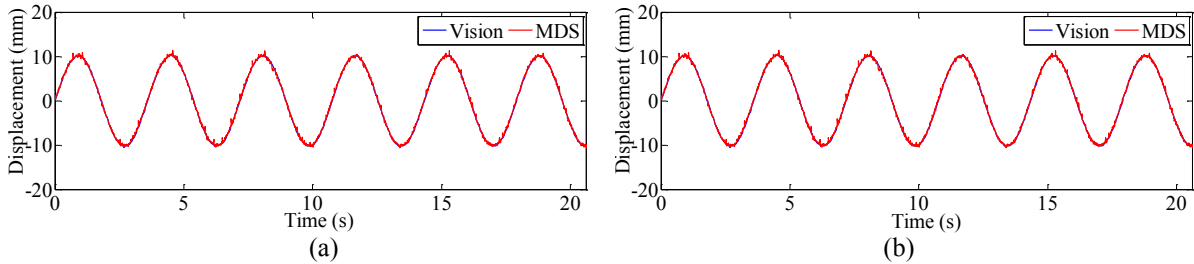


Figure 8 Displacement time histories of case 6: (a) P1, (b) P2

CONCLUSIONS

In this study, a vision-based system is developed for non-contact structural dynamic displacement monitoring. Experimental investigations were carried out on a shaking table, and the performance of the developed vision-based system with two kinds of vision targets was verified by a comparative study between the vision-based system and the MDS. Through analyzing the influence factors, it is indicated that the measurement accuracy and stability of the vision-based system will be affected by illumination when the vision targets are QR codes. When the LED lamps are regarded as the vision targets, the vision-based system shows a strong robustness under different illumination levels. For an accurate and stable monitoring of the structural dynamic displacement with the vision-based system, an appropriate vision target is important. In the future, field tests will be carried out to validate the robustness of the developed vision-based system under more complex environmental conditions (e.g., fog, wind, rain, ground vibration, etc.).

ACKNOWLEDGMENTS

The work described in this paper was jointly supported by the National Science Foundation of China (Grant No. 51308493) and the Research Fund for the Doctoral Program of Higher Education of China (Grant No. 20130101120080).

REFERENCES

- Fukuda, Y., Feng, M.Q. and Shinozuka, M. (2010). "Cost-effective vision-based system for monitoring dynamic response of civil engineering structures", *Structural Control and Health Monitoring*, 17, 918-936.
- Ma, S.P., Pang, J.Z. and Ma, Q.W. (2012). "The systematic error in digital image correlation induced by self-heating of a digital camera", *Measurement Science and Technology*, 23(2), 025403.
- Ni, Y.Q., Ye, X.W. and Ko, J.M. (2010). "Monitoring-based fatigue reliability assessment of steel bridges: analytical model and application", *Journal of Structural Engineering*, ASCE, 136(12), 1563-1573.
- Ni, Y.Q., Ye, X.W. and Ko, J.M. (2012). "Modeling of stress spectrum using long-term monitoring data and finite mixture distributions", *Journal of Engineering Mechanics*, ASCE, 138(2), 175-183.
- Schreier, H.M. and Sutton, M.A. (2002). "Systematic errors in digital image correlation due to undermatched subset shape functions", *Experimental Mechanics*, 42(3), 303-310.
- Ye, X.W., Ni, Y.Q., Wong, K.Y. and Ko, J.M. (2012). "Statistical analysis of stress spectra for fatigue life assessment of steel bridges with structural health monitoring data", *Engineering Structures*, 45, 166-176.
- Ye, X.W., Ni, Y.Q. and Yin, J.H. (2013a). "Safety monitoring of railway tunnel construction using FBG sensing technology", *Advances in Structural Engineering*, 16(8), 1401-1409.
- Ye, X.W., Ni, Y.Q., Wai, T.T., Wong, K.Y., Zhang, X.M. and Xu, F. (2013b). "A vision-based system for dynamic displacement measurement of long-span bridges: algorithm and verification", *Smart Structures and Systems*, 12(3-4), 363-379.
- Ye, X.W., Yi, T.H., Dong, C.Z., Liu, T. and Bai, H. (2015). "Multi-point displacement monitoring of bridges using a vision-based approach", *Wind and Structures*, 20(2), 315-326.
- Yoneyama, S., Kikuta, H., Kitagawa, A. and Kitamura, K. (2006). "Lens distortion correction for digital image correlation by measuring rigid body displacement", *Optical Engineering*, 45(2), 023602.