

Monitoring Bridge Dynamic Deformation in Vibration by Digital Photography

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Abstract. This study adopts digital photography to monitor bridge dynamic deformation in vibration. Digital photography in this study is based on PST-TBPM (photographing scale transformation-time baseline parallax method). Firstly, we monitor the bridge in static as a zero image. Then, we continuously monitor the bridge in vibration as the successive images. Based on the reference points on each image, PST-TBPM is used to calculate the images to obtain the dynamic deformation values of these deformation points. Results show that the average measurement accuracies are 0.685 pixels (0.51mm) and 0.635 pixels (0.47mm) in X and Z direction, respectively. The maximal deformations in X and Z direction of the bridge are 4.53 pixels and 5.21 pixels, respectively. PST-TBPM is valid in solving the problem that the photographing direction is not perpendicular to the bridge. Digital photography in this study can be used to assess bridge health through monitoring the dynamic deformation of a bridge in vibration. The deformation trend curves also can warn the possible dangers over time.

1. Introduction

Deformation monitoring is an important content to assess bridge health [1]. The increase of the bridge flexibility makes it more important to monitor the dynamic deformation of a bridge [2]. But the traditional surveying methods [3, 4], physical sensors [5], GPS (Global Positioning System) [6-8] and the three-dimensional laser scanning [9, 10] have their limitations to monitor the dynamic deformation of a bridge.

However, digital photography [11-13] can monitor the dynamic deformation of a bridge as it monitors a bridge by a digital camera. Although digital photography has not been as popular in bridge structures as in other fields, many pioneering applications in this field have illustrated the potential for growth [14-16]. These examples suggest that digital photography has a unique advantage in monitoring bridge dynamic deformation.



The aims of this study are to monitor the dynamic deformation of a bridge in vibration by digital photography based on PST-TBPM (photographing scale transformation-time baseline parallax method) and to assess bridge health based on the deformation trend of a bridge.

2. Digital photography

For solving the problem-the photographing direction perpendicular to the bridge, PST-TBPM was proposed in digital photography (Figure 3). It also corrected the errors caused by the change of intrinsic and extrinsic parameters of digital cameras. But it requires that the photographing direction is perpendicular to the reference plane. The reference plane does not coincide with the object plane.

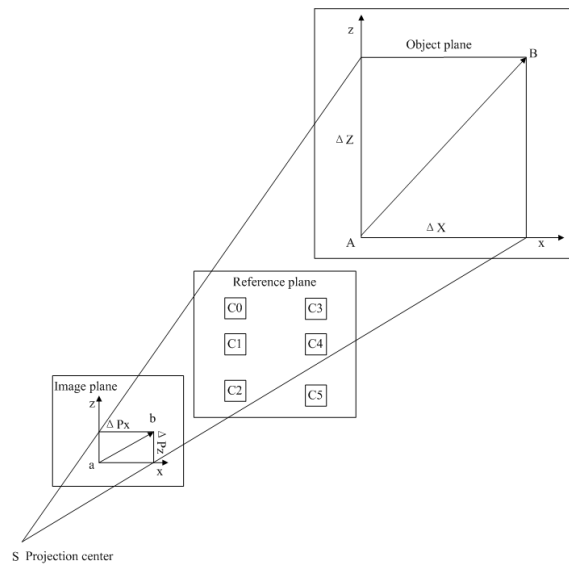


Figure 1. Photographing scale transformation-time baseline parallax method

Reference plane in Figure 1 consists of six reference points labeled as C0-C5. It is used to match images and eliminate the parallax.

Thus, we obtained the deformations based on the photographing scale M:

$$\left. \begin{aligned} \Delta X_R' &= \frac{SA}{Sa} \Delta P_x' = M \Delta P_x' \\ \Delta Z_R' &= \frac{SA}{Sa} \Delta P_z' = M \Delta P_z' \end{aligned} \right\} \quad (1)$$

Where M is the photographing scale on the reference plane, SA and Sa are the photographic distance and the focus respectively, $(\Delta P_x', \Delta P_z')$ are the corrected displacements of the deformation point on the image plane. $\Delta X_R'$ and $\Delta Z_R'$ are the corrected horizontal and vertical deformation of deformation point on the reference plane.

Then, the actual deformations are obtained by the coefficient of the photographing scale transformation:

$$\left. \begin{aligned} \Delta X' &= \Delta is \cdot \Delta X_R' \\ \Delta Z' &= \Delta is \cdot \Delta Z_R' \end{aligned} \right\} \quad (2)$$

Where Δis is the coefficient of the photographic scale transformation, $(\Delta X', \Delta Z')$ are the corrected actual deformations of the deformation point on the object plane.

3. Bridge test

Figure 2 shows Caiyuan road bridge which is a footbridge. It is 102.52 meters in length, 17.8 meters in width. Its span is 92.04 meters.

Before the test, one digital camera (SONY350) was set on the north of Xiaoqing river and the deformation points labeled as U0-U7 were lay on the bridge evenly. Moreover, the reference system formed by the reference points labeled as C0 to C7 was set near the camera, whose photographing direction is perpendicular to the reference system.



Figure 2. Test field of the bridge

The test process is detailed as follows:

- (1) Camera SONY350 was used to monitor the bridge in static as a zero image.
- (2) Camera SONY350 was used to monitor the bridge every three seconds as the successive images when the bridge was in vibration.

4. Data analysis

Due to the calculation, the measurement accuracy data is detailed in Table1. M is the photographing scale on the reference system. The average measurement accuracies are 0.685 pixels and 0.635 pixels in X and Z direction, respectively. As the photographing scale is 0.74mm/pixel, the measurement accuracies are 0.51mm and 0.47mm in X and Z direction, respectively. The measurement accuracy of PST-TBPM reaches sub-millimetre.

In order to assess the bridge health visually, the deformation trend curves of the bridge (Figure3 and 4) are depicted over time based on these dynamic deformation data.

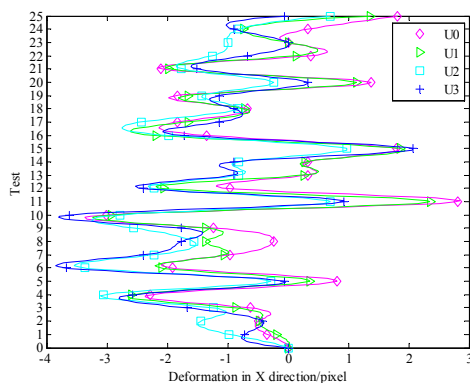
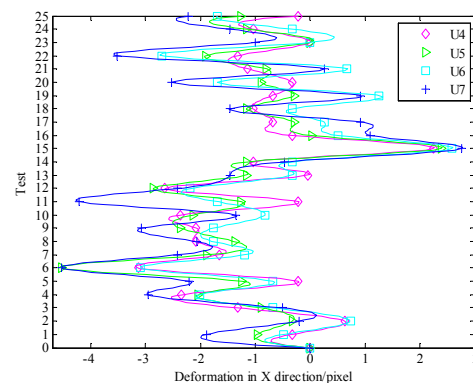
Figure3 shows that the maximal deformation in X direction is 4.53 pixels which develop on U5 and U7 in Test 6. The deformation trend of each point on the major structure of the bridge conforms to each other in X direction, and they are in elastic. This suggests the well connection among the bridge components.

Figure4 shows that the maximal deformation in Z direction is 5.21 pixels which develop on U7 in Test 15. The deformation trend of one deformation point on bridge major structure conforms to each other in Z direction, and they are in elastic. This suggests a good rigidity of bridge.

Thus, Caiyuan road bridge is safety.

Table 1. Measurement accuracy

Test	C6		C7		M/(mm/pixel)
	X/pixel	Z/pixel	X/pixel	Z/pixel	
1	0.52	0.74	0.14	0.70	0.74
2	0.34	0.96	0.31	0.93	0.74
3	0.46	0.43	0.81	0.75	0.74
4	0.40	0.58	0.94	0.91	0.74
5	0.47	0.97	1.18	1.30	0.74
6	0.62	0.22	0.38	0.56	0.74
7	0.02	0.70	0.05	1.42	0.74
8	0.24	0.22	1.25	0.56	0.74
9	0.25	0.70	1.25	1.41	0.74
10	0.65	0.22	0.27	0.56	0.74
11	0.47	0.22	1.18	0.44	0.74
12	0.02	0.07	0.95	0.76	0.74
13	0.13	0.17	1.12	1.23	0.74
14	0.13	0.70	1.12	1.41	0.74
15	1.50	1.37	2.49	0.36	0.75
16	0.52	0.32	1.14	0.37	0.74
17	0.86	0.43	1.45	0.75	0.74
18	1.13	0.30	1.12	0.42	0.74
19	0.14	0.05	0.45	0.73	0.74
20	0.54	0.45	0.81	0.25	0.74
21	0.13	0.70	0.25	1.42	0.74
22	0.46	0.22	1.81	0.56	0.74
23	1.00	0.67	1.00	0.06	0.74
24	0.14	1.22	0.12	0.56	0.74
25	0.47	0.22	1.18	0.56	0.74
Average	0.46	0.51	0.91	0.76	0.74

**(a)****(b)****Figure 3.** Deformation trend curves of deformation points in X direction

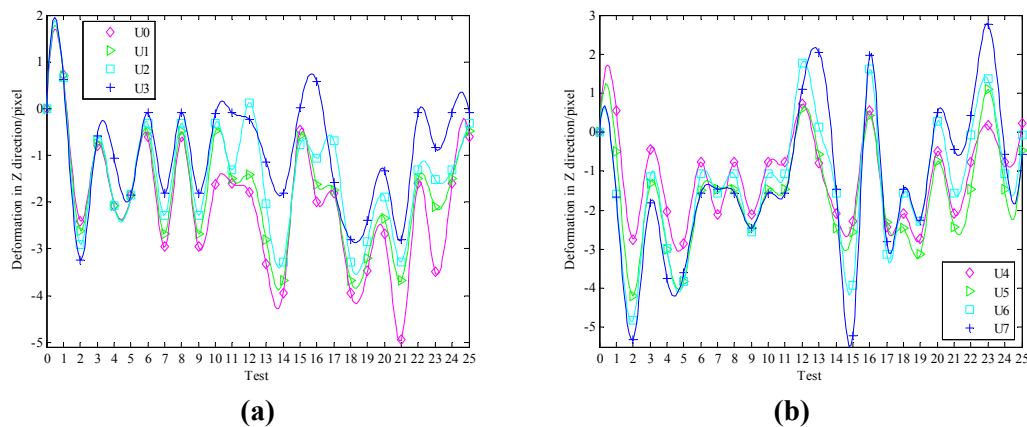


Figure 4. Deformation trend curves of deformation points in Z direction

5. Conclusion

This study uses digital photography based on PST-TBPM to monitor dynamic deformation of the bridge in vibration. Deformation trend curves of the bridge are depicted based on these dynamic deformation data. Through analyzing these test results, the following conclusions are obtained:

(1) The measurement accuracy of PST-TBPM reaches the sub-millimeter. The measurement accuracies are 0.51mm and 0.47mm in X and Z direction, respectively.

(2) The position (U7) vibrates strongly than others. Its maximal deformations in X and Z direction are 4.53 pixels and 5.21 pixels.

(3) The deformation trend of each point on the major structure of the bridge conforms to each other in X and Z direction, and they are in elastic. Caiyuan road bridge is safe.

PST-TBPM breaks the limitation that the photographing direction has to be perpendicular to the bridge when the time baseline parallax method was used in digital photography. Digital photography in this study can monitor the dynamic deformation of a bridge and depict deformation trend curves of the bridge over time to assess the bridge health and to warn the possible dangers. Digital photography will be a conventional method to monitor bridge dynamic deformation in the future.

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