Observing Bridge Dynamic Deflection in Green Time by Information Technology

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Abstract. As traditional surveying methods are limited to observe bridge dynamic deflection; information technology is adopted to observe bridge dynamic deflection in Green time. Information technology used in this study means that we use digital cameras to photograph the bridge in red time as a zero image. Then, a series of successive images are photographed in green time. Deformation point targets are identified and located by Hough transform. With reference to the control points, the deformation values of these deformation points are obtained by differencing the successive images with a zero image, respectively. Results show that the average measurement accuracies of C0 are 0.46 pixels, 0.51 pixels and 0.74 pixels in X, Z and comprehensive direction. The average measurement accuracies of C1 are 0.43 pixels, 0.43 pixels and 0.67 pixels in X, Z and comprehensive direction in these tests. The maximal bridge deflection is 44.16mm, which is less than 75mm (Bridge deflection tolerance value). Information technology in this paper can monitor bridge dynamic deflection and depict deflection trend curves of the bridge in real time. It can provide data support for the site decisions to the bridge structure safety.

1. Introduction

Bridges are an important link of transportation network, which bears vehicle dynamic loads every time. As the bridge flexibility increases with its span and scale, they are vulnerable to produce deflection deformation caused by the external dynamic load. Deflection deformation is an important index of bridge health. It is of great importance to grasp bridge deflection in time. This drives an urgent need to observe dynamic deflection of bridge structures in the running state.

The traditional surveying methods cannot observe bridge dynamic deflection deformation over time. Physical sensors can only observe bridge local deformation. GPS (Global Positioning System) cannot meet the accuracy requirements of dynamic deflection observation [1]. The three-dimensional laser scanning [2] is limited to monitor instantaneous deformation of bridge structures.

However, information technology [3] can observe bridge dynamic deflection. It includes digital photography and computer technique. Although digital photography has not been as popular in bridge structures as in other fields such as biomechanics, chemistry, biology, as well as architecture, many pioneering applications in this field have illustrated the potential for growth. Kim [4] used digital photography to observe the deformation of Wisconsin state highway bridge. Abdel-Sayed et al.

[5]used digital photography to observe the deformation of soil-steel bridge. Zhang [6, 7] used digital photography to monitor bridge structures, and the measurement accuracy was not less than 3‰. These examples show that information technology can meet the accuracy requirement of bridge deformation observation.

The aims of this study are to observe bridge dynamic deflection in green time by information technology and assess bridge health based on these deflection data.

2. Information technology

2.1. Distortion correcting of a digital camera
This study uses a grid method [8] to reduce the distortion of digital cameras to improve measurement accuracy. Figure 1 illustrates that Point A in Figure 1 moves to Point A' caused by the distortion. ΔX and ΔY are horizontal and vertical deformation respectively.
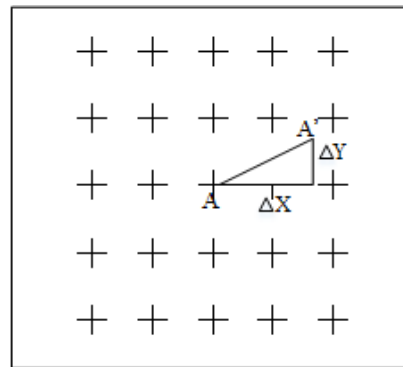

Figure 1. Analysis of distortion error

This study adopted the direct linear transformation method [9, 10] to verify the measurement accuracy of the digital camera. Table1shows that the differences between the distance calculated and the distance measured are at the range of 0 to1 millimetre, and the relative precision is up to 2‰, which is achieved by comparing the difference to the corresponding distance measured.

Table 1. Measurement accuracy

Line	Distance calculated/mm	Distance measured/mm	Difference/mm
U0-U2	588	589	1
U1-U3	596	595	1
U2-U4	599	599	0

2.2. Hough Transform to identify the circles
Hough transform is the core of information technology used in this study, which decides the measurement accuracy in the test. For a higher identification accuracy, we use binary image processing to discard useless information of the initial image and highlight target boundaries. Then, we got binary image of the initial image.

Finally, Hough Transform and the least square criterion are used to identify the circles and locate its core, respectively.

Assume that the circle is centered on (x_0, y_0), and r is circle radius, (x_i, y_i) is an arbitrary point on the circle. The circle equation is expressed as:

$$(x_i - x_0)^2 + (y_i - y_0)^2 = r_i^2 \tag{1}$$

It can also be expressed as:

$$r_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} \tag{2}$$

Where r is observed value, (x_0, y_0) is the unknown number.

Initial value of (x_0, y_0) is obtained by averaging the point (x_i, y_i) on the circle. Error equation is expressed as:

$$v_i = -\frac{x_i - x_0^0}{\sqrt{(x_i - x_0^0)^2 + (y_i - y_0^0)^2}}\delta x_0 - \frac{y_i - y_0^0}{\sqrt{(x_i - x_0^0)^2 + (y_i - y_0^0)^2}}\delta y_0 + f(x_0^0, y_0^0) - r_i \tag{3}$$

Where $(\delta x_0, \delta y_0)$ is the error value of (x_0, y_0)

3. Bridge test

Figure 2 shows that Fenghuangshan road bridge is a self-balanced reinforced concrete, central bearing frame arch. It is of beautiful appearance and it takes good use of the material properties and mechanical properties of the concrete structure. It is 31.5-meters wide. Its span is 18+60+18 meters. The main arch is steel tube concrete, which is the most important compression member. The bridge panel consists of precast concrete and cast-in-place concrete. The arch concrete structure is a large volume concrete.

Figure 2. Illustrte of bridge test

Before the test, we set up the observe station and lay observation points in proper place. In red time, we use digital cameras to observe the bridge as a zero photo, and the successive photos are obtained in green time. In Figure 2, deformation points from U0 to U7 are arranged based on stress analysis of a bridge in green time. Control points from C0 to C3 are used to form a reference plane, which is used to calculate baseline data. Table 2 shows the spatial coordinates of these control points.

Table 2. Spatial coordinates of control points

Point Name	X/m	Y/m	Z/m
C0	914.784	960.05	97.314
C1	914.973	958.228	97.647
C2	994.319	996.286	99.454
C3	994.405	996.332	98.921

4. Data analysis

In the test, the control points do not move. Thus, their pixel displacements are zero in theory. However, their pixel displacements are not zero through using information technology to calculate these photos. Their pixel displacements therefore are viewed as measurement accuracy. Table 3 shows the measurement accuracy of C0 and C1. In Table 3, X0, Z0 and SQRT($X0^2+Z0^2$) represent X, Z and comprehensive direction of C0. X1, Z1 and SQRT($X1^2+Z1^2$) represent X, Z and comprehensive direction of C1. The average measurement accuracies of C0 are 0.46 pixels, 0.51 pixels and 0.74 pixels in X, Z and comprehensive direction. The average measurement accuracies of C1 are 0.43 pixels, 0.43 pixels and 0.67 pixels in X, Z and comprehensive direction.

Table 3. Measurement accuracy/pixel

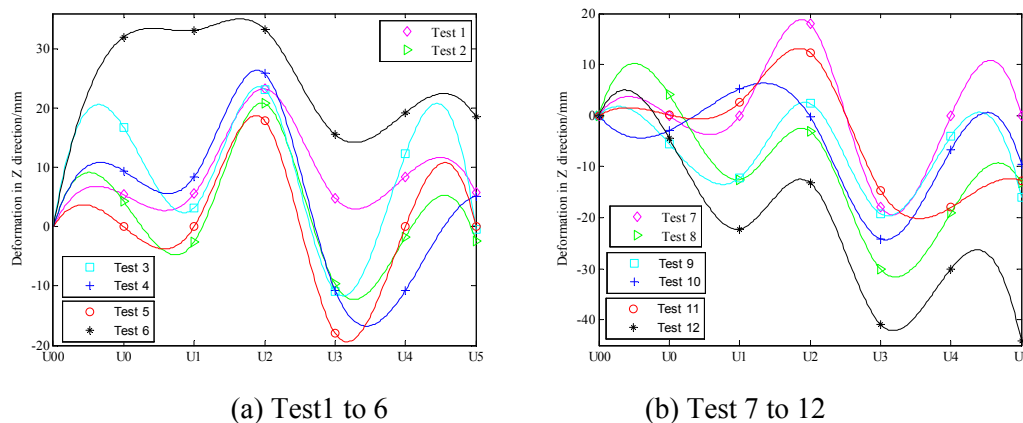| Test	C0			C1		
	X0	Z0	SQRT($X0^2+Z0^2$)	X1	Z1	SQRT($X1^2+Z1^2$)
1	0.20	0.46	0.50	0.79	0.53	0.95
2	0.68	0.93	1.15	0.33	0.07	0.34
3	0.67	0.05	0.67	0.35	0.05	0.35
4	0.39	0.49	0.63	0.40	0.49	0.63
5	0.44	1.00	1.09	0.46	1.00	1.10
6	0.61	0.97	1.15	0.40	1.04	1.11
7	0.44	1.00	1.09	0.46	0.00	0.46
8	0.40	0.07	0.41	0.41	0.07	0.42
9	0.39	0.03	0.39	0.40	0.03	0.40
10	0.22	0.50	0.55	0.23	0.49	0.54
11	0.28	0.04	0.28	0.71	0.97	1.20
12	0.78	0.56	0.96	0.23	0.42	0.48
Average	0.46	0.51	0.74	0.43	0.43	0.67

After identifying and locating deformation point targets by Hough transform, we get actual deformation of deformation points by differencing the successive images with a zero image respectively with reference to the control points on each photo. In order to analyzing bridge dynamic deflection in green time, Table 4 shows the actual deformation values of some deformation points from U0 to U5. The negative represents that the deformation point moves down. The positive represents that the deformation point moves up.

The maximal bridge deflection is 44.16mm, which is less than bridge deflection tolerance 75mm (L/1000). L represents the bridge span.

In order to analyze the bridge deflection trend in green time, the bridge deflection trend curves (Figure 3) are depicted based on bridge deflection data. The bridge deflection trend curves are approximate to some sinusoidal-cosinusoidal curves. These phenomena conform to the deformation law caused by vehicle dynamic load, and the bridge deflections are within the elastic. Fenghuangshan road bridge therefore is safety.

Table 4. Actual deformation (/mm) of deformation points

Test	U0/mm	U1/mm	U2/mm	U3/mm	U4/mm	U5/mm
1	5.41	5.56	23.30	4.88	8.47	5.76
2	4.28	-2.57	20.82	-9.62	-1.73	-2.35
3	16.78	3.22	23.21	-10.87	12.26	-0.42
4	9.40	8.42	25.86	-10.68	-10.76	5.17
5	0.00	0.00	17.96	-17.96	0.00	0.00
6	32.01	33.15	33.38	15.55	19.22	18.56
7	0.00	0.00	17.96	-17.96	0.00	0.00
8	4.15	-12.54	-3.05	-30.08	-19.10	-13.18
9	-5.53	-12.21	2.37	-19.23	-4.05	-16.07
10	-2.93	5.20	-0.20	-24.17	-6.70	-9.47
11	0.13	2.55	12.36	-14.64	-18.00	-12.70
12	-4.42	-22.20	-13.19	-40.91	-30.00	-44.16

(a) Test1 to 6   (b) Test 7 to 12

Figure 3. Bridge dynamic deflection trend curves in green time

5. Conclusion

This study use information technology to observe bridge dynamic deflection. In the data processing, Hough transform is adopted to identify the deformation point targets and locate their cores firstly. Then, the actual deformations of deformation points are adopted by differencing the successive images with a zero image respectively with reference to the control points on each photo. Through analyzing the bridge deflection data, the following conclusions are obtained:

(1) The measurement accuracy reaches sub-pixel level. The average measurement accuracies of C0 are 0.46 pixels, 0.51 pixels and 0.74 pixels in X, Z and comprehensive direction. The average measurement accuracies of C1 are 0.43 pixels, 0.43 pixels and 0.67 pixels in X, Z and comprehensive direction.

(2) The maximal bridge deflection is 44.16mm, which is less than bridge deflection tolerance 75mm (L/1000). L represents the bridge span.

(3) Fenghuangshan road bridge is safety. The bridge deflection trend curves are approximate to some sinusoidal-cosinusoidal curves in green time and the bridge deflections are within the elastic.
Information technology proves valid in observing bridge dynamic deflection and depicting deflection trend curves of the bridge in real time. It also can provide data support for the site decisions to the bridge structure safety. It will be a conventional method of bridge health observation in the future.

Acknowledgments

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