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Monitoring Dynamic Deflection Deformation of a Bridge by Digital Photography

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Abstract. In order to make up the deficiency for traditional surveying method in monitoring bridge dynamic deformation in real time, in this paper, we propose the method of IM-PST (image matching-photographic scale transformation) method based on digital photogrammetry: the observation stations (cameras) were set at appropriate location. The reference plane formed by the reference points, were 2.6-meters away from the camera and deformation points were set on the bridge. In real time the bridge deflections were obtained through transforming the pixel changes on the image plane of deformation points based on the IM-PST method. Results show that the maximum deflection of the bridge is 3.472mm and 4.980mm in the upward and downward respectively. And both of them are within the allowable deflection of the bridge (L/1000, L is the bridge span). Thus, the Caiyuan Bridge is in good operation.The IM-PST system can make a safety warning for the bridge in real time and provide data support to repair the bridge.

1. Introduction

With the rapid development of science and technology, the structure and scale of bridges are becoming more and more complex. As the operating time increases, Traffic load, Foundation settlement, The influence of Bridge's own factors, causing deformation of some components of the bridge structure,the bridge damage when the deformation reaches the yield point. Therefore, it is necessary to carry out long-term and real-time monitoring for the bridge, and then grasp the dynamic deformation of the bridge in time, and effectively warn the bridge collapse and other safety accidents.

At present, the methods, such as level, theodolite, total station and so on, are still important means of monitoring, but these methods with a heavy workload, the distribution of points is limited by the conditions of the terrain, The operation is cumbersome and cannot be automatically monitored, recorded and calculated and multiple deformation points cannot be monitored at the same time [1]; Collimation strain and tilt measurements, the measurements process are simple and can be used to monitor the deformation inside the body, also it is easy to automate, but it only provide local deformation information [2]; Sensor measurement can monitor bridges in real time, but need direct contact with bridge; Although GPS technology can complete monitoring, recording and calculation automatically, but it needs to set up GPS receivers or antennas at each monitoring point. The cost is higher and monitoring is strongly influenced by the outside world, not suitable for more monitoring points of Long-span bridges; 3D laser scanning can monitor multiple points and realize automatic monitoring, but the monitoring period is too long to monitor dynamically in real time [3]; In summary, The current monitoring methods can not realize the characteristics of simple, fast, accurate, automatic, real-time and not limited by observation conditions to monitor the deformation for multiple points at the same time.

With the development of digital photography technology and the improving of digital camera, fusion image processing and computer technology, in this paper, we propose a method of IM-PST method, Using high-pixel non-measurement digital camera as monitoring equipment, pasting the deformed point mark on the sensitive parts of the bridge, Setting 6 reference points near the bridge to form a reference plane. The system able to capture the deformation information of the bridge continuously; We studied and developed the health monitoring and warning system, it can be used to observe the inaccessible bridge body, don't affect the construction and send the data to your laptop in real time for processing; The photos are rich in information and can be preserved for a long time.It is easy to implement comparison analysis of bridge deformation, then obtain the deformation rules of each monitoring point of Caiyuan bridge under variable load. It provides reference data for bridge safety warning and makes up the deficiency that the traditional measurement method can not monitor the instantaneous deformation of multiple deformation points at the same time.

2. The system of Bridge deformation Monitoring

2.1. Correction of camera distortion

In order for the actual scene to be correctly imaged in the system, it is necessary for the image and the actual scene to be strictly satisfied with the pinhole imaging model, but there must be a difference between the lens made up of multiple lenses and the principle of pinhole imaging, this is the aberration of lens. Especially at the edge of the image, barrel distortion often occurs in the lens of wide-angle, however, the pincushion distortion often occurs in the telephoto lens [4]. After analyzing the distortion difference by using the grid method in this experiment we obtained a analysis graph about distortion difference. We study on multi-group distortion difference get the law of its change and complete the correction of distortion error [5].

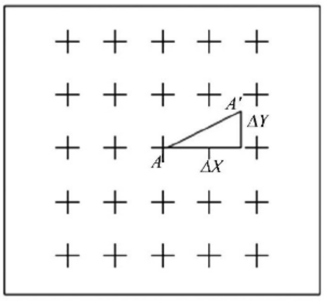


Figure 1. Correction of distortion error.

The steps for correcting distortion error are as follows:

First: fixing grids and setting up a digital camera at a certain distance away from the grid;

Second: taking photographs in the center of the grid by a camera, simultaneously recording the distance between the camera and the grid;

Third: comparing the clearer picture with the actual grid, observing the feature points in the photograph, analysis of the magnitude and direction of distortion;

Fourth: moving the camera to different distances repeat the second and third steps;

Fifth: deducing the correlation between distortion errors based on the work of the first four steps, then eliminating the distortion.The mathematical relationship is as follows:

$$\left.\begin{aligned} \Delta x &= (x - x_0) r^2 K_1 \\ \Delta z &= (z - z_0) r^2 K_1 \\ r &= [(x - x_0)^2 + (z - z_0)^2]^{\frac{1}{2}} \end{aligned}\right\} \tag{1}$$

In formula (1):$\Delta x, \Delta z$ are the correction term of objective lens distortion difference; x, z are the coordinate of the image points; x_0, z_0 are Coordinates of image main points; K_1 is undetermined coefficients of distortion of symmetric objective lens; r is radius vector.

2.2. Elimination of camera parallax by time baseline parallax method

Fixing photography station, based on the time baseline parallax method, taking two different photos at two different times as a Image sequences, measuring the parallax at the same point, the parallax times the photo scale coefficient is the actual displacement of the target point [6]. The time baseline parallax method requires that the internal and external azimuth elements of the photographs taken in different periods keep completely consistent, otherwise, he deflection changes will be wrong. However, it is impossible to keep the internal and external azimuth elements completely consistent due to the existence of various errors [7], this paper proposes a method by setting 8 stable reference points in a direction perpendicular to the direction of the photographic light and closer to the photographic to eliminate the measurement parallax.（x_0, z_0, P_{x0}, P_{z0}）,（x_1, z_1, P_{x1}, P_{z1}）, ……（x_7, z_7, P_{x7}, P_{z7}）, are the coordinates and the visual difference of the image plane of points. C0, C1, C2, C3, C4, C5, C6, C7setting up the average image plane of reference points. Camera parallax correction:

$$\left.\begin{aligned} P_x &= a_x x + b_x z + c \\ P_z &= a_z x + b_z z + d \end{aligned}\right\} \tag{2}$$

In formula (2): P_x, P_z are the parallax difference of reference points in the x and z direction of the average image plane; a_x, b_x, a_z, b_z are Parallax coefficient in the direction of x and y; x, y are the Image plane coordinates of reference points; c, d are the fixed coefficient of Parallax In the direction of x and y.

Obtained the parallax of the average image plane based on the reference point, correction it to the deformation point on the image plane, then obtain the corrected displacement value.

$$\left.\begin{aligned} \Delta P'_x &= \Delta P_x - P_x \\ \Delta P'_z &= \Delta P_z - P_z \end{aligned}\right\} \tag{3}$$

2.3. Monitoring principle

In this paper, data processing by the method of IM-PST. When a point on the object is deformed from A to B, the deformation $\Delta X, \Delta Z$ are as follows:

$$\left.\begin{aligned}\Delta X &= M\Delta P_x^{'} \\ \Delta Z &= M\Delta P_Z^{'}\end{aligned}\right\} \tag{4}$$

In Formula(4): M is the photographic scale, ΔX , ΔZ are Horizontal and vertical deformation values of monitored points on the object plane, ΔP_x , ΔP_z are values after correction on the image plane of monitored points in the direction of Horizontal and vertical [5].

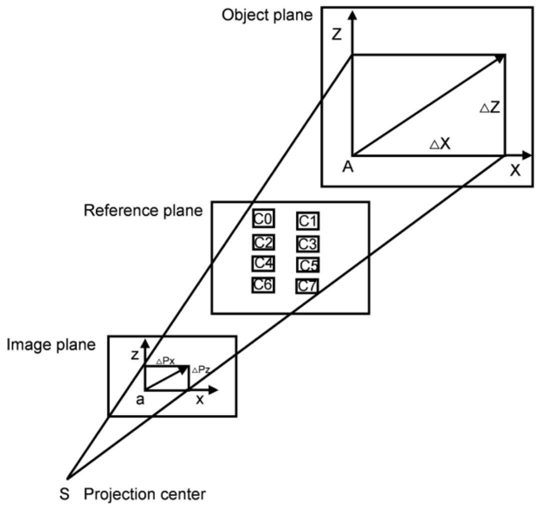


Figure 2. Image matching -Photography Proportional Transformation method.

3. Bridge test

3.1. Bridge introduction

Caiyuan Bridge is located on the west side of Huaxianchang Road, the span reach 92.04+10.48meters and the width of the bridge is 17.8 meters. The main structure is a arch bridge with basket type and self-balanced steel concrete, the side span is simply supported beam bridge with hollow slab, the foundation is bored pile foundation, the design standard of pavement load is 3.5KPa.

3.2. Bridge experiment

The load-bearing structure of the bridge is the main beam, it is easily to be affected by the impact of the water flow and the dynamic load of the vehicle and the bridge is prone to deformation in the mid-span area. So, in order to monitor the deformation of the bridge effectively, the deformation point is placed in the position where the force is larger and the deformation is easier to occur. According to the above analysis, the deformation points are arranged from north to south on the bridge are U0, U1, U2, U3, U4, U5, U6, U7. Setting 8 stable reference points about 2.6 meters away from the camera and perpendicular to the digital camera, the reference points are C0, C1, C2, C3, C4, C5, C6, C7; Setting the reference point C8, C9 on one side of the bridge. The monitoring steps are as follows:

(1)When there is no load on the bridge, taking a photograph as a zero image.

(2)Making a large crane vibrate on the bridge after monitoring begins, continuous shooting the bridge with a digital camera, 1 monitoring per second, got 18 photos in total.

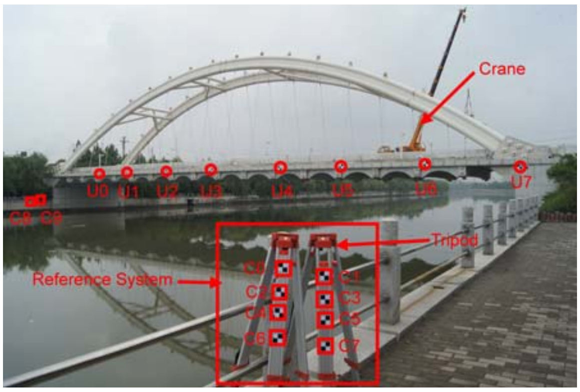


Figure 3. Caiyuan bridge Experiment.

3.3. Data processing and results analysis

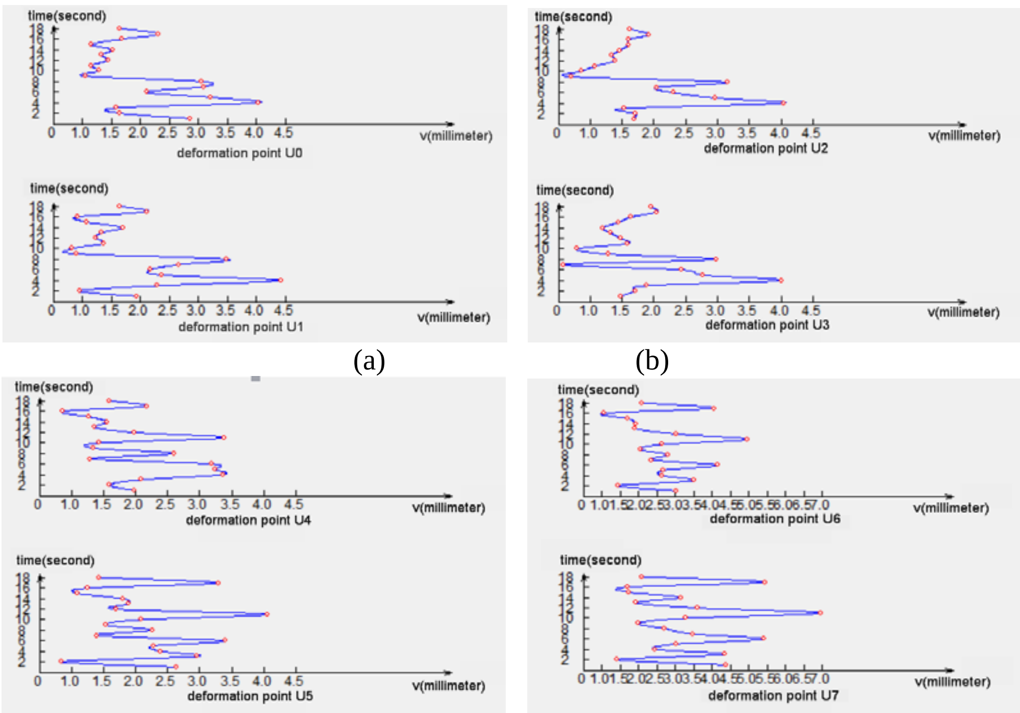
To calculate the deflection of the deformation point. Firstly, making the photographs obtained by photogrammetry convert into BMP format, using ACDSEE Image processing Software [5], then putting the monitoring dates into processing software for image matching and numbering. Re-adding the processed zero and subsequent photos to the deformation monitoring system and enter the corresponding reference baseline and baseline length, calculate it automatically. Getting the measuring accuracy in x and z directions and average accuracy of reference points C0, C1, C8 and C9 as Table 1. At the same time obtain the deformation data and deformation diagram of each deformation point as table 2 and figure 4.

Table 1. Measuring accuracy of reference point/pixel.

C0		C1		C8		C9	
X	Z	X	Z	X	Z	X	Z
0.546	0.397	0.092	1.004	0.202	1.720	0.259	1.991
0.675		1.008		1.732		2.008	

Table 2. Relative offset of observation points in the first set of photographs/pixel.

Test	U0	U1	U2	U3	U4	U5	U6	U7
1	-0.63	-0.39	-0.02	0.39	1.03	2.59	3.36	5.16
2	-1.5	-0.49	-1.48	-1.46	-1.44	-0.42	0.61	0.63
3	1.08	2.2	1.38	1.57	1.87	3.13	3.5	4.78
4	-3.95	-4.63	-4.16	-3.6	-2.77	-1.01	0.03	1.23
5	-0.5	-0.49	-0.47	-0.46	-0.44	0.58	0.6	0.62
6	1.08	1.2	1.38	1.57	2.87	3.14	3.5	4.78
7	3.47	2.9	2.07	0.11	-0.35	-0.66	-1.46	-3.46
8	-2.22	-2.03	-2.74	-1.41	-0.91	-0.46	1.17	1.85
9	0.73	0.54	0.27	-1.05	-0.53	-0.96	-0.56	-0.23
10	0.37	0.43	-0.49	-0.4	0.75	1.87	2.04	3.17
11	0.85	1.17	0.64	1.17	2.97	3.69	4.68	6.64
12	-0.63	-0.39	-1.02	0.39	1.03	1.59	3.36	4.16
13	0.5	0.51	0.52	-0.46	0.56	1.58	1.61	1.63
14	-1.36	-1.17	-0.9	-0.58	-0.11	1.32	1.92	3.56
15	0.5	-0.49	-0.47	-0.46	0.56	0.58	1.6	1.62
16	-1.5	-0.49	-1.48	-1.46	-0.44	0.58	-0.39	0.63
17	-1.86	-1.41	-1.76	-1.01	1.12	3.14	3.55	5.03
18	-1.5	-1.49	-1.48	-1.46	-1.44	-0.42	-0.39	0.63



(c) (d)

Figure 4. Deflection diagram of deformation point.

4. Conclusions

According to the IM-PST method we can obtain the deflection value of the monitoring points. The following conclusions can be drawn from the analysis of the experimental results:

(1)The experiment result accords with the variation rule that inversely proportional relation between precision and distance. The reference point C0, C 1 is located in the vertical direction of the camera about 2.6meters away from the digital camera, the accuracy is 0.675pixel and 1.008pixels respectively; the reference point C8, C9 are on the bridge about 118 meters away from the center of photography, the accuracy is1.732pixels and 2.008pixels.

(2)According to the IM-PST, we can obtain the pixel variation of each deformation point. At the same time we can get ratio coefficient M, it means each pixel represents the field distance 0.75mm. Thus, the instantaneous deformation of each deformation point can be calculated under the dynamic load and its own load.

(3)According to the data, we concluded that the Caiyuan Bridge is in the safe operation period. The maximum deflection of upward is 4.63pixels, that's 3.472mm; the maximum deflection of downward deformation is 6.64pixels, that's 4.98mm; the dates far less than the allowable deflection of the bridge (L / 1000).

(4)We can be judge that the Caiyuan Bridge is in the elastic stage, and has strong stiffness according to the results. It can be concluded from the bridge deformation diagram that the points of U5, U6 and U7 is close to the crane and subjected to vibration force is larger than which is far from the crane during the vibration process. U6 is right under the crane, the deformation is greater than the point U5 which is farther away from the crane. U7 is the supporting point of bridge, when the bridge is forced, it transfers the force to the supporting point U7, so the force of U7 is greater than that of other points, but the deformation is restored instantly, this indicates that Caiyuan Bridge is in the stage of elasticity.

(5)According to the data, bridge monitoring system generates the deflection diagram of each deformation point automatically. We can see the instantaneous deformation and relative deformation of each point in the process of loading; At the same time, we also can obtain the superposition graph of several deformation points in the same time period, intuitively judge the load on each part of the bridge under dynamic load and the law of deformation with time, so as to provide data analysis on the structural optimization of the bridge.

The monitoring system is simple to operate, non-contact measurement, and does not affect the normal construction and use of the project, can monitor the whole bridge at the same time, the precision up to 3‰. According to the deformation graph can analyze the bridge deformation in real time, fast and intuitively. The system provide data support for healthy use and later maintenance of bridges, it is easier to popularize in engineering.

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References
[1] Junping Zhang. Bridge detection [M]. Beijing: Chinacommunication press, 2002.
[2] Xiaohua Wang,Youjian Hu,Liu Bai.Review of deformation monitoring research [J]. Science of Surveying and Mapping, 2006 (02): 130-132+9.
[3] Youyi Xiong,Yijin Chen,Zhixin Feng,Yan Li. The Research on Load-Generated Deformation Monitoring of Sanshan South Bridge Based on Terrestrial Laser Scanning [J]. Mapping and spatial geographic information, 2012, 35 (08): 26-29+33.
[4] Siyi Zeng. Separation method of damage factor based on deflection measurement of prestressed concrete bridge [D]. Guangzhou University, 2016.
[5] Guojian Zhang,Chengxin Yu,Guangli Guo.Application of digital close-range photogrammetry in the deformation observation of check gate [J]. Journal of Shandong University (engineerring science), 2017, 47 (06): 46-51.
[6] Yuanzhong Luan,Fakui Lv, et al.Monitoring and forecasting of dynamicdeformation [M]. Beijing: China Agriculture Scientech Press , 2007: 9-11.
[7] Yan Li, Chengxin Yu.The Research on the Deformation Monitoring System of Steel Structure Based on Digital Photogrammetry[D].Wuhan: Wuhan UUniversity,2001.
[8] Guojian Zhang,Guangli Guo, Chengxin Yu, et al. Application of Rapid Photogrammetry system in observing vibration deformation of bridge [J]. Highway, 2017, (9): 93-197.