CRACK MONITORING USING A DIGITAL CAMERA AND AN IMAGE TOTAL STATION

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ABSTRACT: There are many bridges in Japan due to geographic characteristic. Japanese government spends much budget for the maintenance of them. If the crack monitoring of bridges is possible, maintenance cycle of bridges can be expected with high accuracy. Therefore accurate maintenance cycle of bridge structures can be calculated based on the crack monitoring data. Kochi University of Technology is developing crack monitoring system using an eight mega pixel SLR digital camera. To survey cracks on a bridge structure, it is necessary to attach control points on the bridge structure. In some cases, it may be impossible to attach control points, if bridge structure height is too high. An image total station was used to solve the problem because image total station can acquire coordinate of a target with an image which describes the measured point. The images which have measured positions were used as control points for the exterior orientation of the digital camera. The corresponding points of image control points in stereo images were matched by least square matching method. The space intersection of the stereo image to calculate three dimensional coordinates of cracks was carried out by the least square matching. The accuracy of three dimensional measurement was evaluated by the image total station measurement. Millimeter accuracy could be obtained in the three dimensional crack measurement using the digital camera and image total station.

KEYWORDS: Close range monitoring, GIS, Spatial database,

1. INTRODUCTION

Many bridges are exiting in Kochi prefecture due to the geographic characteristic of Shikoku Island, Japan. The bridge structures located near the sea are much suffered from Nacl from the sea. Japan is spending much budget for the maintenance of infrastructures. Therefore deciding maintenance cycle of infrastructure is very important.

To survey cracks on a bridge structure using a digital camera, it is necessary to attach control points on the bridge structure. In some cases, it may be impossible to attach control points if bridge structure's height is too high.

An image total station was used in this study to solve the problem because image total station can acquire coordinate of a target with an image which describes the measured point.
The images taken by image total station were used as control points (ICP: image control point) for the exterior orientation of the digital camera. After that the orientation results was evaluated by comparing their three dimensional measurement accuracy with image total station measurements.

The objective of this study is to evaluate the photogrammetric measurement accuracy of crack measurement using image control points taken by an image total station.

2. MEASUREMENT DEVICES

2.1 Digital Camera

In this study, eight mega pixel resolution Single Lens Reflex (SLR) camera which produced by cannon was used for photogrammetric measurement of a concrete structure. Table 1 shows the specification of the camera used.

Table 1. The specification of cameras used

CCD size	Focal length	Resolution
22.7×15.1mm	25mm	3072 × 2048

2.2 Image Total Station

Total station is a combination of theodolite (angle measurement) and an electronic distance measuring device (EDM). Therefore, total station enables us to measure angle and distance at the same time.

Image total station can measure distance and angle with a picture which describes the measured point.

3. CAMERA CALIBRATION

Camera calibration is seriously necessary process for using a camera in a measurement. The camera calibration was carried out by using Photo modeler 4.0. the coefficients of lens distortions were calculated by the Photo modeler.

Most of commercial camera shows serious radial lens distortion. Figure 1 shows an example of lens distortion. Figure 2 shows how the lens distortion corrected.

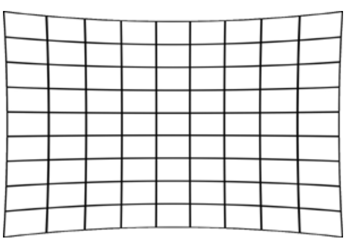

Figure 1. Radial lens distortion

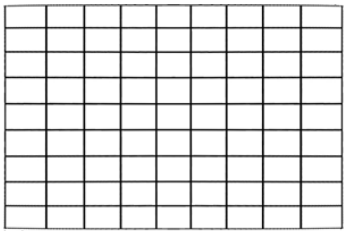

Figure 2. After the correction of lens distortion

A pair of stereo images was taken by the camera. Figure 3 shows left hand side image. Figure 4 shows right hand side image.

Figure 3. Left hand side image

Figure 4. Right hand side image

4. THE CALIBRATION OF IMAGE TOTAL STATION

4.1 Noise reduction

Photos produced by the image total station contains stripe noise, therefore the noise should be eliminated. Figure 5 shows an example of stripe noise

The stripe noise could be eliminated by averaging pictures by redundant measurements (Equation 1).

$$\text{Averaged image}= \frac{\sum_{i=1}^{N} image_i}{N}$$

Equation 1. Calculation for averaged image where N is number of images.

Figure 5. Photo taken by the image total station

Figure 6 shows the noise reduced image. The stripe noise could be removed by averaging the images taken by the image total station.

Figure 6. Noise reduced image

4.2 Brightness adjustment

The corners of the pictures taken by the image total station are darker than inside. A white object was taken, then the amount of brightness offset was calculated. Figure 7 shows the brightness offset image.

Figure 7. Brightness offset image

In adjustment, pixel value of brightness offset image was added to a target image. Figure 8 shows a target image to be adjusted. Brightness values of figure 7 and 8 were combined. Figure 9 shows the result of bright adjustment of Figure 8.

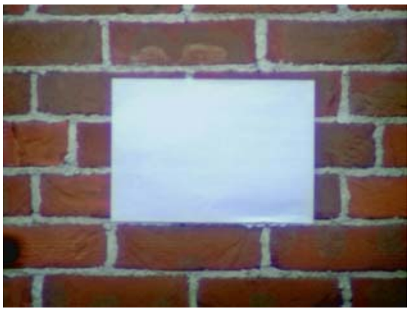

Figure 8. A target image to be adjusted by the brightness offset image.

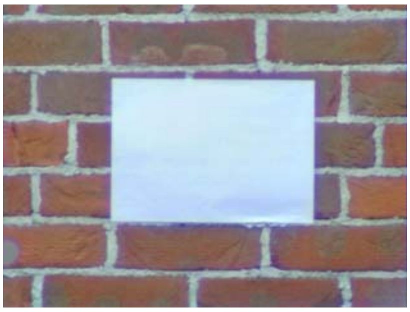

Figure 9. After brightness adjustment of the Figure 8

5. THREE DIMENSIONAL CRACK MEASUREMENT

Accurate three dimensional measurement depends on 1) the accuracy of image matching and 2) the accuracy of exterior orientation of a camera.

Totally four image control points were taken by the image total station. Figure 10 shows the four image control points and an image taken by the digital camera.

5.1 Least squares matching

For exterior orientation of a camera, control points are required. The control points were measured by image total station. Corresponding points of measured control points in photos taken by a digital camera were matched by least square image matching method.

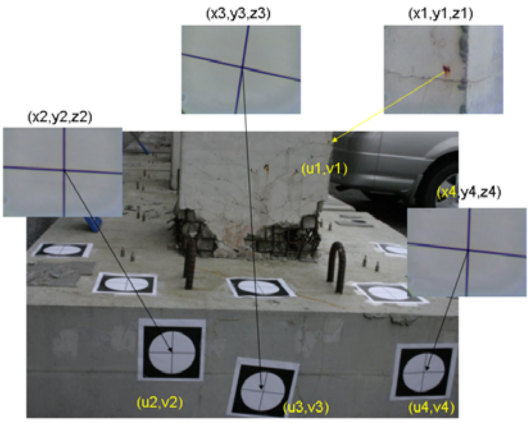

Figure 10. Image control points taken by the image total station

Least square matching method searches the corresponding points by changing the shape and brightness of template image. Equation 2 shows the mathematical description of least squares matching.

$$g_t(x, y) = h_0 + h_1 \times g_s[(a_0 + a_1 x + a_2 y), (b_0 + b_1 x + b_2 y)]$$

Equation 2 least squares matching equation

g_t: target window
g_s: template window
e: error vector
h_0,,h_1: unknown coefficients for brightness adjustment
a_0,a_1,a_2,b_0,b_1,b_2: unknown coefficient for geometric transformation

This equation is a nonlinear equation; therefore this equation was linearized by Taylor series. Initial values for unknowns were input to the linearized equation, then iterative calculation carried out until the correction of the initial input minimized to be fall in global optimization.

Minimum four control points were required for the exterior orientation of a digital camera, least squares image matching of four image control points were carried out.

5.2 Exterior camera orientation

For accurate three dimensional measurement, the accurate position and attitude of camera is required. The position and attitude of camera is calculated by the collinearity equation (Equation 3).

The collinearity equation means that the object in image coordinate space and the object in object coordinate space are existing in a ray.

$$x + \Delta x = -f \frac{a_{11}(X - X_o) + a_{12}(Y - Y_o) + a_{13}(Z - Z_o)}{a_{31}(X - X_o) + a_{32}(Y - Y_o) + a_{33}(Z - Z_o)}$$

$$y + \Delta y = -f \frac{a_{21}(X - X_o) + a_{22}(Y - Y_o) + a_{23}(Z - Z_o)}{a_{31}(X - X_o) + a_{32}(Y - Y_o) + a_{33}(Z - Z_o)}$$

Equation 3 collinearity equation

where
x and y: photo coordinate;

f: focal length

$\Delta x, \Delta y$: the correction of lens distortions;

X, Y and Z : the coordinate in object space;

Xo, *Yo* and *Zo* : the coordinate of a camera; *i* is point number;

$a_{11} = \cos\omega\cos\phi$;

$a_{12} = \cos\omega\cos\kappa + \sin\omega\sin\phi\cos\kappa$;

$a_{13} = \sin\omega\sin\kappa - \cos\omega\sin\phi\cos\kappa$;

$a_{21} = -\cos\phi\sin\kappa$;

$a_{22} = \cos\omega\cos\kappa - \sin\omega\sin\phi\cos\kappa$;

$a_{23} = \sin\omega\cos\kappa + \cos\omega\sin\phi\sin\kappa$;

$a_{31} = \sin\phi$;

$a_{32} = -\sin\omega\cos\phi$ and $a_{33} = \cos\omega\cos\phi$.

The knowns are image coordinate and object space coordinate of a target object, and unknowns are the position and attitude of camera.

This equation is nonlinear problem; therefore the equation should be linearized in Taylor series. The optimum initials were input, then iterative calculation was carried out.

Table 2 and table 3 show the orientation results of right image and left image.

Table 2 The orientation result of right image

X(m)	Y(m)	Z(m)
0.010657	-0.887418	0.455425
Omega (degree)	Phi (degree)	Kappa (degree)
72.13485	-7.799178	0.379806

Table 3 The orientation result of left image

X(m)	Y(m)	Z(m)
-0.219093	-0.92756	0.45729
Omega (degree)	Phi (degree)	Kappa (degree)
73.451863	-16.433997	-4.582743

6. THREE DIMENSIONAL MODEL RECONSTRUCTION

After exterior orientation, three dimensional model reconstruction carried out. The three dimensional coordinate of a target object could be obtained by intersecting normal vectors from the two exterior oriented camera stations (Figure 11).

Three dimensional crack measurement was carried out using the digital camera, then the result was compared with the measurement result by the image total station.

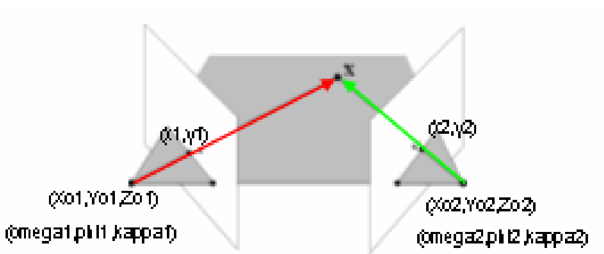

Figure 11. Three dimensional model reconstruction by intersecting normal vectors from the two oriented camera station.

Figure 12 shows measured point of the first crack target by the image total station. Table 4 shows the measurement evaluation of the first crack target: maximum 0.48mm measurement error was shown in this measurement.

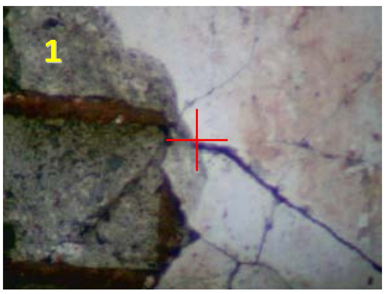

Figure 12 Crack target 1 measured by the image

total station.

Table 4. Evaluation of crack 1 measurement by the digital camera

	X (m)	Y (m)	Z (m)
TRUE	0.12239	0.40169	0.14539
By image control	0.12363	0.39701	0.14054
Error	-0.00124	0.00468	0.00485

Figure 13 shows measured point of the second crack target by the image total station. Table 5 shows the measurement evaluation of the first crack target: maximum 0.56mm error was shown in this measurement.

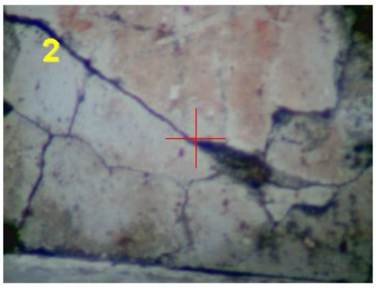

Figure 13 Crack target 2 measured by the image total station.

Table 5 Evaluation of crack 2 measurement by the digital camera

	X (m)	Y (m)	Z (m)
TRUE	0.17988	0.39777	0.12704
By image control	0.18251	0.40581	0.12043
Error	-0.00262	-0.00804	0.00661

Figure 14 shows measured point of the third crack target by the image total station. Table 6 shows the measurement evaluation of the first crack target: maximum 0.8mm error was shown in this measurement.

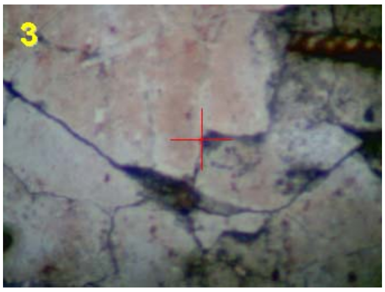

Figure 14 Crack target 3 measured by the image total station.

Table 6 evaluation of crack 3 measurement by the digital camera

	X (m)	Y (m)	Z (m)
TRUE	0.16358	0.39723	0.12178
By image control	0.16487	0.39845	0.11614
Error	-0.00129	-0.00122	0.00564

7. CONCLUSIONS

In this study, crack measurement method using a digital camera and an image total station was introduced. Crack measurement using image control point taken by an image total station showed millimeters accuracy.

8. REFERENCES

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