EVALUATION OF IMAGE BASED INTEGRATED MEASUREMENT SYSTEM AND ITS APPLICATION TO TOPOGRAPHIC SURVEY

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ABSTRACT:

A convenient 3D measurement using amateur digital camera is enormously expected in various fields with appearance of the low cost and high-resolution amateur digital cameras. In these circumstances, there are many software for digital photogrammetry on the market in Japan. However, there are still problems for efficient digital photogrammetry. These problems include distance measurement for absolute orientation and interior orientation which should be performed beforehand, and these restrictions should be removed for ideal convenient photogrammetry using amateur digital cameras.
With this objective, Image Based Integrated Measurement System called as IBIM system was developed by the authors. The most remarkable point of the system is its ability to calculate both of exterior and interior orientation parameters without scale distance nor Ground Control Points which have exact 3D coordinates in object field.
This paper focuses the IBIM system and its performance evaluations, and it is verified that accuracy is not influenced by distance numbers, and both accuracy of horizontal and vertical shows almost same values compare with standard error. Furthermore, topographic surveying such as cliff, where is needed non-contact measurement was achieved using IBIM system and it is concluded from the view point of non-contact measurement and convenience that the IBIM system is expected to become a useful system for the various close range application fields.

1. INTRODUCTION

There are many digital cameras which have more than 5 mega pixels on the market in Japan. In these circumstances, a convenient 3D measurement using amateur digital camera is enormously expected from various fields, and there are many software for digital photogrammetry on the market.
In these circumstances, performance evaluations for the amateur digital cameras were investigated by the authors from the view point of digital Photogrammetry. The authors also have been concentrating on developing a convenient 3D measurement method using amateur digital camera, and software “3DiVision” was designed to perform convenient 3D measurement. However, there were some issues for practical 3D measurement using amateur digital camera. These problems were distance measurement for giving scale in absolute orientation and interior orientation which should be performed beforehand, and these restrictions should be removed for ideal convenient photogrammetry using amateur digital camera.
In order to remove these restrictive conditions and to promote a convenient digital photogrammetry using amateur digital camera, Image Based Integrated Measurement System which is called as IBIM system was developed, and calibration method was investigated by the authors (Odake and Chikatsu, 2004). The most remarkable point of the system is its ability to calculate both exterior and interior orientation parameters simultaneously without scale distance nor GCP.
After the IBIM system and its performance evaluations, and it is verified that accuracy is not influenced by distance numbers, and both accuracy of horizontal and vertical shows almost same values compare with standard error. Furthermore, topographic surveying such as cliff, where is needed non-contact measurement was achieved using IBIM system and it is concluded from the view point of non-contact measurement and convenience that the IBIM system is expected to become a useful system for the various close range application fields.

2. IBIM SYSTEM

The IBIM system consists of amateur digital camera (OLYMPUS C-770 Ultra Zoom, 4.0 mega pixels) and laser distance meter (Leica DISTO Lite 4, accuracy is ±3mm to 100m), and it is able to rotate in vertically and horizontally so that precise distance from centre of the camera to the feature points on object field can be measured, and images are record

Figure 1. Appearance of the IBIM system

on SD memory card of the camera. Furthermore, camera and laser axis can be precisely adjusted using 4 adjusting screw on the eaves. Figure 1 shows an appearance of the IBIM system, and Figure 2 shows configuration of the system.

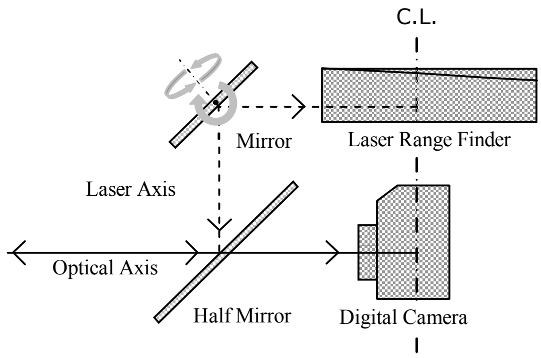

Figure 2. Configuration of the IBIM system

3. ORIENTATION METHOD

3.1 Camera Calibration

In order to perform camera calibration, at least 6 distances from center of the camera to the points which show feature on object have to be measured by the laser distance meter. These feature points are defined as temporal GCP in this paper. Then, 37 unknown parameters such as exterior orientation parameters for both camera $\{(X_{OL}, Y_{OL}, Z_{OL}, \omega_L, \varphi_L, \kappa_L), (X_{OR}, Y_{OR}, Z_{OR}, \omega_R, \varphi_R, \kappa_R)\}$, interior orientation parameters $\{f$ (focal length), x_0, y_0 (principal points), a_1, a_2 (scale factor), k_1, k_2 (lens distortion)$\}$ and 3D coordinates for 6 temporal GCPs should be calculated. Generally, number of unknown parameters become $19+3n$ (n: number of temporal GCPs), and these unknown parameters are calculated by collinearity condition and distances simultaneously under the geometric condition that one point is origin point and X direction is given. For example, 3D coordinate is given as $P_1(0,0,0)$ for origin point and X direction is given as $P_2(X_2,0,0)$ in the Figure 3. Then, $19+3n-5$ becomes unknowns against $2n$(distances)+ $2\times 2n$ (collinearity) conditions, and these unknowns can be calculated as the values which make following function H minimum under the least square method.

$$H = \sum_{i=1}^{M} \sum_{j=1}^{N} \left(p_1\left(\Delta x_{ij}^2 + \Delta y_{ij}^2 \right) + p_2\left(\Delta D_{ij}^2 \right) \right) \Rightarrow \min \tag{1}$$

where, Δx, Δy: residuals for image coordinate, ΔD: residuals for distance, M: number of temporal GCP, N: number of image, p_1,p_2: weight

Here, collinearity condition is shown as equation (2), and distance condition is shown as equation (3).

$$\begin{cases} x = f \dfrac{m_{11}(X-X_0)+m_{12}(Y-Y_0)+m_{13}(Z-Z_0)}{m_{31}(X-X_0)+m_{32}(Y-Y_0)+m_{33}(Z-Z_0)} \\ y = f \dfrac{m_{21}(X-X_0)+m_{22}(Y-Y_0)+m_{23}(Z-Z_0)}{m_{31}(X-X_0)+m_{32}(Y-Y_0)+m_{33}(Z-Z_0)} \end{cases} \tag{2}$$

where, x, y: image coordinate, X, Y, Z: Ground coordinate、m_{11}-m_{33}: Rotation matrix

$$D_i = \sqrt{(X_i - X_0)^2 + (Y_i - Y_0)^2 + (Z_i - Z_0)^2} \tag{3}$$

Furthermore, radial polynomial 5th degree was adapted to correct lens distortion in this paper (Fryer J. G. and Brown D.C, 1986).

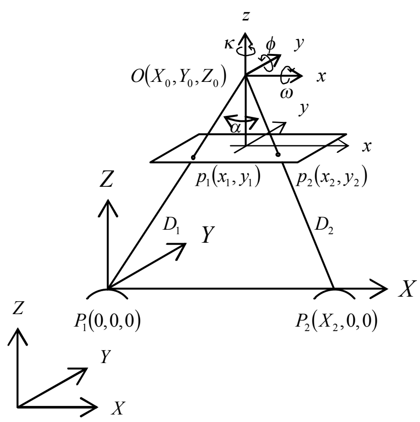

Figure 3. Geometry in the IBIM

However, initial values for camera position are required as same as orientation parameters in camera calibration, and these are obtained by following procedures.
Let make D_1 and D_2 in Figure 3 shows measured distances, angle α is computed with respect to focal length (f) and image coordinates by equation (4),

$$\cos\alpha = \frac{x_{p1}\cdot x_{p2} + y_{p1}\cdot y_{p2} + f^2}{\overline{Op_1}\cdot\overline{Op_2}} \tag{4}$$

where, $\overline{Op_1} = \sqrt{\left(x_{p1}^2 + y_{p1}^2 + f^2\right)}$, $\overline{Op_2} = \sqrt{\left(x_{p2}^2 + y_{p2}^2 + f^2\right)}$

and initial value X_2 for the point P_2 according to the origin point P_1 (0, 0, 0) is computed as L from following equation (5).

$$L = \overline{P_1P_2} = \sqrt{D_1^2 + D_2^2 - 2\cdot D_1\cdot D_2\cdot\cos\angle\alpha} \tag{5}$$

Therefore, right and left camera position O (X_0, Y_0, Z_0) can be estimated respectively as follows under assumption that vertical photo was taken over flat terrain.

$$\begin{aligned} X_0 &= \left(D_1^2 - D_2^2 + L^2\right)/2L \\ Y_0 &= D_1\cdot\sin\left(-\left(\left(y_{p2} - y_{p1}\right)/f\right)\right) \\ Z_0 &= D_1^2 - X_0^2 - Y_0^2 \end{aligned} \tag{6}$$

However, initial value for camera position which are computed from above equation (6) are value that are obtained under vertical photo. Then, initial value for exterior orientation parameters (camera position and attitude except κ) are recomputed using collinearity condition for P_1 and P_2, and distance for D_1 and D_2. κ is estimated in this step as 0°since the IBIM is set up on tripod with levelling function.
After above procedure, initial values for temporal GCPs for P_3 to P_n are computed using initial exterior orientation parameters,

then self-calibration are performed by equation (1) using initial values and equal weight (p_1=p_2=1).

3.2 Measurement using the IBIM

Figure 4 shows measuring concept by the IBIM. After imaging at left position (A), distances for the *n* (6 in Figure 4) temporal GCPs are measured by rotating the IBIM, and repeat same procedures at right position (B).

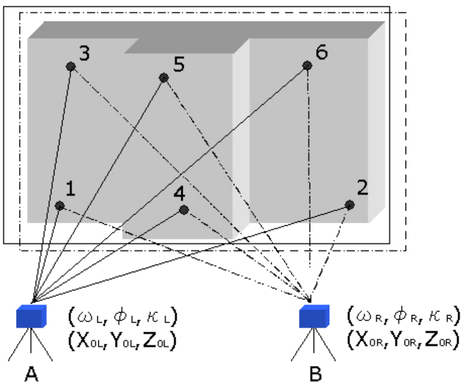

Figure 4. Concept of measurement by the IBIM

4. PERFORMANCE EVALUATION OF IBIM

4.1 Accuracy of IBIM system

In order to evaluate the IBIM system, test target (H: 640mm, W: 480mm, D: 50mm) was used. Figure 5 shows test target. Each black circle point was manufactured with 0.05mm accuracy and 42 points (intersection of grid) were used as check points, and these image coordinates were obtained as area gravity by image processing procedures. Furthermore, the authors were investigated that the accuracy of the IBIM was influenced by number of temporal GCPs.
Point [1] means origin point such as P_1, and point [3] shows X axis such as P_2 in Figure 3. white numbered points were temporal GCPs, and image coordinate for these points were measured by manually with pixel size since spot size of laser have more one pixel size.
Stereo image was taken about 1.0m altitude respectively and 0.4 m base line under focal length was fixed, and distances were measured.

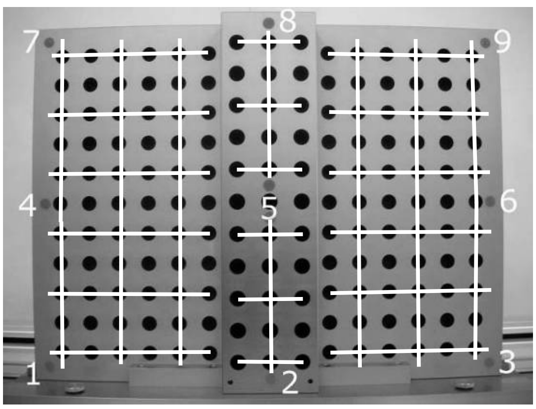

Figure 5. Test Target

Table 1 shows root mean square error for 42 check points. σ_{XY} means horizontal error and σ_Z means vertical error. Standard error which computes from equation (7) using altitude, base line, focal length and pointing accuracy is wildly used in photogrammetry to estimate accuracy (Fraser, 1996).

$$\sigma_{XY} = \left(\frac{H}{f}\right)\sigma_p \quad , \quad \sigma_Z = \left(\frac{H}{f}\right)\left(\frac{H}{B}\right)\sigma_p \qquad (7)$$

where, *H*: altitude, *f*: focal length, *B*: base line, σ_p: pointing accuracy and it was estimated as 0.003mm in this paper.

Table 1. Accuracy of IBIM system

Num. of Temp GCPs	σ_{XY}	σ_Z
6 (No. 1,2,3,7,8,9)	± 0.661	± 1.018
7 (No. 1,2,3,5,7,8,9)	± 0.922	± 1.091
8 (No. 1,2,3,4,6,7,8,9)	± 0.607	± 1.141
9 (No. 1,2,3,4,5,6,7,8,9)	± 0.673	± 1.048
Standard error	± 0.407	± 1.019

Unit: mm

Form Table 1, it can be said that both accuracy for XY and Z coordinate shows good results, and it is concluded that the calibration method was effective method for the IBIM. From this result, the accuracy of IBIM is not influenced by number of temporal GCPs.
By the way, in the orientation method of the IBIM which were developed by the authors, it is performed to optimize number of temporal GCPs. Figure 6 shows the relationship between residual errors and degree of freedom of orientation method. From figure 6, with the increase of number of temporal GCPs and freedom of degree of orientation method, summation of squares of residual errors is also increasing. However, it can be seen that horizontal and vertical error are as same as standard error from Table 1. Furthermore, considering that unbiased variance of residual errors (the value that square of residual errors are divided by degree of freedom) are constant, the accuracy of IBIM in each number of temporal GCPs is constant. Therefore, the numbers of temporal GCPs which IBIM system should be measured in measurement object space are enough as 6 points for effective use of IBIM system.

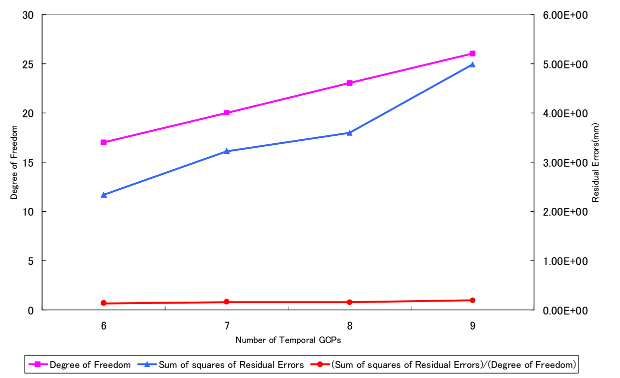

Figure 6. Residual errors and degree of freedom

4.2 Internal reliability of orientation result

For evaluating orientation method, the internal reliability of orientation result was investigated in this paper. Table 2 shows internal reliability of 3D coordinates of temporal GCPs in each

number of temporal GCPs. Here, internal reliability is square root of average variance which is calculated by the estimated value of variance-covariance matrix of orientation parameters such as exterior and interior orientation parameters and 3D coordinates of temporal GCPs. In addition, it is an index to show geometric stabilities.
From this result, Comparing horizontal and vertical values, vertical values are better than horizontal ones. It is estimated that vertical 3D coordinates of temporal GCPs are restricted by measured distance from IBIM system. However, horizontal and vertical internal reliability are stabilized in each number of temporal GCPs. Therefore, internal reliability is not influenced by number of temporal GCPs. Furthermore, the numbers of temporal GCPs are also enough as 6 points for effective use of IBIM system.

Table 2. Internal reliability

Num. of Temp GCPs	σ_{XY}	σ_Z
6 (No. 1,2,3,7,8,9)	1.5358	0.4563
7 (No. 1,2,3,5,7,8,9)	1.4632	0.4317
8 (No. 1,2,3,4,6,7,8,9)	1.6225	0.4160
9 (No. 1,2,3,4,5,6,7,8,9)	1.7177	0.4941

5. APPLICATION TO TOPOGRAPHIC SURVEYING

In order to investigate an adaptability of the IBIM system to measuring and recording of complex geography, cliff (Figure 7) was measured by the IBIM.

Figure 7. Cliff

It is recorded topographic map of cliff in this paper. Furthermore, in order to investigate measurement result of IBIM system, it is compared with a result measured by Terrestrial Laser Scanner (LD90-3100VHS-FLP (Riegl)). In addition, both IBIM system and Terrestrial Laser Scanner were measured from distance (flying altitude) of 15m.
Figure 8 shows topographic map from IBIM system and Figure 9 shows topographic map from Terrestrial Laser Scanner. Figure 8 and 9 are drawn as 5cm pitch contour maps, since standard error of this case which estimated by equation (7) is 2.1 cm. there are crowds of contour lines from figure 9, this is estimated measurement errors such as branches and woodbines. From both results, topographic surveying such as cliff, where is needed non-contact measurement was achieved using IBIM system and it is concluded from the view point of non-contact measurement and convenience that the IBIM system is expected to become a useful system for the various close range application fields.

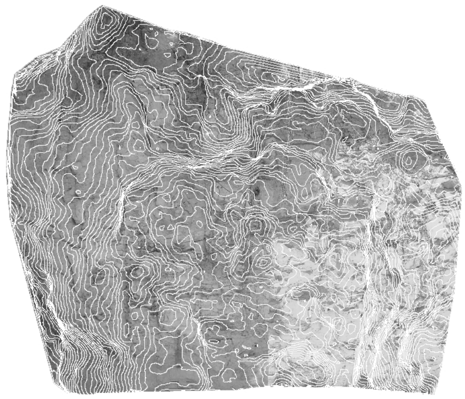

Figure 8. Topographic map from IBIM system

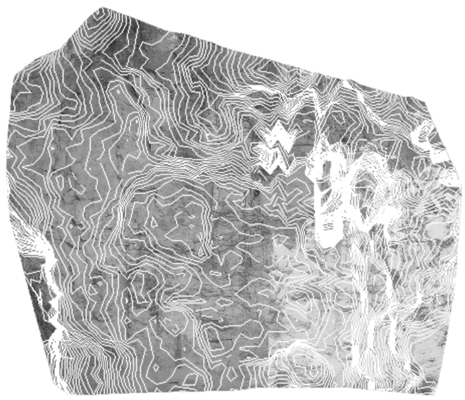

Figure 9. Topographic map from Terrestrial Laser Scanner

6. CONCLUSIONS

The Image Based Integrated Measurement (IBIM) System using digital camera and laser distance meter was developed by the authors for a convenient digital photogrammetry, and performance evaluation was investigated in this paper.
Therefore, it is concluded that the IBIM is expected to become a useful measurement system for the various close range application fields since interior orientation parameters and exterior orientation parameters are calibrated simultaneously without any scale distances nor GCPs on object field.
There are issues, however, for further work. These problems are image matching procedures for 3D modelling and integration of 3D models.

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