DEVELOPMENT OF INTEGRATED PHOTOGRAMMETRIC SYSTEM AND ITS APPLICATION TO 3D MODELING

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ABSTRACT:

A convenient 3D measurement using amateur digital cameras is enormously expected in various fields with appearance of high-resolution amateur digital cameras. In these circumstances, software for low-cost digital photogrammetry "3DiVision" was designed to perform convenient 3D measurement using amateur digital cameras. However, there are still issues for efficient digital photogrammetry. These problems are distance measurement for absolute orientation and previous interior orientation, and these restrictions should be removed for ideal convenient photogrammetry using amateur digital cameras.
With this motive, Image Based Integrated Measurement (IBIM) System was developed by the authors. The most remarkable point of this IBIM is its ability to calculate both exterior and interior orientation parameters simultaneously without distance measurement, GCP and previous interior orientation procedures. After the IBIM system and performance evaluation are briefly discussed, its application to 3D modelling is demonstrated in this paper.

1. INTRODUCTION

The change in photogrammetry from analog to digital means change from film to CCD (Charge Coupled Device) sensor, and real-time imaging became possible. CCD, which has been invented in 1970's, is one of the electric charge transfer devices in semiconductor, and its resolution was about only 10K bytes at the first stage. However, there are various high-resolution armature digital cameras which have more than 3 mega pixels on the market nowadays, and 43,400,000 sets of amateur digital cameras were shipped in 2003 (CIPA, 2004). On the contrary, 13,930,000 sets of film cameras were shipped. Furthermore, acceleration of downsizing is current trends. In these circumstances, amateur digital cameras are expected to contribute enormously to digital photogrammetric field, and there are various digital photogrammetric software on the market.
In order to perform convenient digital photogrammetry using amateur digital cameras, performance evaluation of 3-mega armature digital cameras has been investigated (Kunii & Chikatsu, 2001), and software "3DiVision" has been designed to perform convenient 3D measurements (Chikatsu & Kunii 2002). Furthermore, application of the 3DiVision to 3D modelling of historical object was also investigated from the viewpoint of digital archives (Nakada & Chikatsu 2003). However, there are still issues for convenient digital photogrammetry become operational. These problems are ground control points, previous interior orientation procedures. Generally, digital photogrammetry is performed using under alternative conditions: Ground control points which have accurate 3D coordinate, scale distance on object field which is needed in absolute orientation, interior orientation procedures which have to performed previously. These restrict conditions should be removed for ideal convenient photogrammetry.
With this motive, Image Based Integrated Measurement (IBIM) System was developed by the authors. The most remarkable point of this IBIM is its ability to calculate both exterior and interior orientation parameters simultaneously without scale distance, GCP and previous interior orientation procedures (Ohdake & Chikatsu 2004). In order to improve measurement accuracy by the IBIM System, new calibration method using distance for 2 temporal GCPs is described in this paper. Furthermore, its application to 3D modelling is investigated.

2. IMAGE BASED INTEGRATED MEASUREMENT SYSTEM

Image Based Integrated Measurement (IBIM) System developed by the authors consists of 5 parts: mirrors, amateur digital camera (3.14 mega pixels), laser range finder (accuracy is ±3mm to 40m), personal computer and monitor. Figure 1 shows the appearance of this system.

Figure 1. Appearance of the IBIM

3. CAMERA CALIBRATION

In order to perform camera calibration, at least 6 space distances for the points, which show feature on object field from the center of a camera, have to be measured by the laser profiler. These feature points are defined as temporal GCP in this paper. Then, 36 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 (lens distortion)$\}$ and 3D coordinates for 6 temporal GCPs should be calculated. These unknown parameters are calculated by collinearity condition and space distances simultaneously. Detail calibration procedures are as follows. Figure 2 shows the concept of measurement by the IBIM.

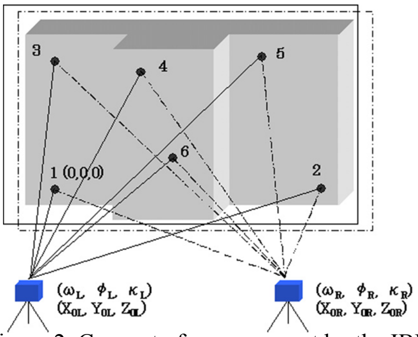

Figure 2. Concept of measurement by the IBIM

3.1 Initial Value

Figure 3 shows the concept of computation of initial values for camera position and the temporal GCPs.

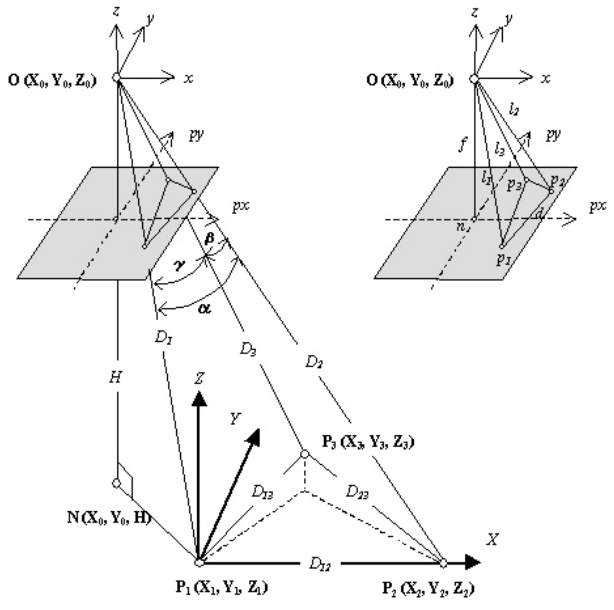

Figure 3. Concept of computation of initial values

3.1.1 Initial Values of Camera Position

Initial values for camera position are required as same as orientation parameters in camera calibration, and these are obtained by following procedures.

In Figure 3, D_1, D_2 and D_3 are space distances, angle α is computed with respect to focal length (f) and image coordinate using following equation (1).

$$\cos\alpha = \frac{x_{p1}\cdot x_{p2} + y_{p1}\cdot y_{p2} + f^2}{\overline{Op_1}\cdot\overline{Op_2}} \quad (1)$$

$\overline{Op_1}$ and $\overline{Op_2}$ are length from the camera position to image points, and the lengths are computed by following equation (2).

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

Therefore, initial value X_2 for the point P_2 according to the origin point P_1 (0, 0, 0) is computed as D_{12} from equation (3).

$$D_{12} = \overline{P_1P_2} = \sqrt{D_1^2 + D_2^2 - 2\cdot D_1\cdot D_2\cdot\cos\angle\alpha} \quad (3)$$

On the contrary, relationship between focal length and flying height (distance from exposure position to the object field) is simply expressed as follows using image distance d_{12} to the corresponding ground distance D_{12} under the assumption that vertical photo was taken over flat terrain.

From the following relation, initial Z coordinate for exposure position is estimated as H by equation (4).

$$\frac{f}{H} = \frac{d_{12}}{D_{12}} \quad (4)$$

Furthermore, let make ground coordinate for the camera position O (X_0, Y_0, Z_0), P_1 (X_1, Y_1, Z_1) and P_2 (X_2, Y_2, Z_2), space distance D_1, D_2 is expressed as follows,

$$D_1^2 = (X_0 - X_1)^2 + (Y_0 - Y_1)^2 + (Z_0 - Z_1)^2 \quad (5)$$

$$D_2^2 = (X_0 - X_2)^2 + (Y_0 - Y_2)^2 + (Z_0 - Z_2)^2 \quad (6)$$

where: $(X_1, Y_1, Z_1) = (0,0,0)$, $(X_2, Y_2, Z_2) = (X_2, 0, 0)$

By equations (5) and (6), initial value for camera position is obtained as follows.

$$\left.\begin{aligned} X_0 &= \left(D_1^2 - D_2^2 + X_2^2\right)/2X_2 \\ Y_0 &= \sqrt{\left(D_1^2 - H^2 - X_0^2\right)} \\ Z_0 &= H \end{aligned}\right\} \quad (7)$$

where: X-axis was defined in the direction of temporal GCPs P_1 to P_2 in this paper.

3.1.2 Initial Value of Temporal GCPs

Coarse initial values of 3D-coordinates for the temporal GCPs are calculated using coplanarity condition and photo scale. This photo scale is given as equation (4), and fine initial values of 3D-coordinates for the temporal GCPs are calculated by equation (8).

$$\left.\begin{aligned} X &= (Z - Z_0)\frac{m_{11}x + m_{21}y - m_{31}f}{m_{13}x + m_{23}y - m_{33}f} + X_0 \\ Y &= (Z - Z_0)\frac{m_{12}x + m_{22}y - m_{32}f}{m_{13}x + m_{23}y - m_{33}f} + Y_0 \end{aligned}\right\} \quad (8)$$

where: x, y are image coordinates of temporal GCPs, X_0, Y_0, Z_0 are camera position and m_{ij} are rotation matrixes.

3.1.3 Initial Values of Orientation Parameters

The initial values of exterior orientation parameters are given as calculated values from the space resection using initial values

for the temporal GCPs, which were obtained by the above procedures.
The initial values of interior orientation parameters; such as a focal length, principal points and scale factor were given as the nominal value, and lens distortion parameter was set to 0 in this stage.

3.2 Calibration Procedures

This calibration procedure means to calibrate the interior orientation parameters, the exterior orientation parameters and the temporal GCPs simultaneously, and the aim of this paper is to improve measurement accuracy using the IBEM.
In order to achieve the aim, distance between temporal GCPs P_1 and P_2, which can be computed by measured distances between camera position and the temporal GCPs is considered as additional condition.
In the above procedure, initial values for the exterior orientation parameters and 3D coordinates for the 6 temporal GCPs are given. Therefore, 36 unknown parameters for the interior/exterior orientation parameters and 3D coordinates for temporal GCPs are calculated by the resection using collinearity conditions, space distances and additional condition.
Equation (9) shows collinearity conditions, and equation (10) shows distance conditions, and these equations for the both images are used simultaneously in calibration procedures. However, in order to obtain convergence solution stability, it is necessary to fix an axis. Therefore, P_1 is defined as the origin point in Figure 2, and the direction from P_1 to P_2 is defined as X axis in this paper. Consequently, 5 unknown parameters are reduced since coordinate for the temporal GCP P_1 and P_2 is given as (0, 0, 0), (X_2, 0, 0) respectively, and 31 unknown parameters are calibrated as the values that make the following function H minimum under the least-squares method (equation (11)). Furthermore, 3D coordinates for additional feature points are able to compute simultaneously.

Collinearity condition:

$$\left.\begin{aligned} F &= (x - x_0)(1 + k_1 r^2) \\ &\quad + f\frac{m_{11}(X - X_0) + m_{12}(Y - Y_0) + m_{13}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)} \\ G &= (y - y_0)(1 + k_1 r^2) \\ &\quad + f\frac{m_{21}(X - X_0) + m_{22}(Y - Y_0) + m_{23}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)} \end{aligned}\right\} \quad (9)$$

where: x, y are image coordinates of temporal GCPs, r is distance from principal point to image point, k_1 is lens distortion parameter, and m_{ij} are rotation matrixes.

Observation condition for the space distance:

$$D = \sqrt{(X - X_0)^2 + (Y - Y_0)^2 + (Z - Z_0)^2} \quad (10)$$

Function with weight:

$$H = \left[p_1(\Delta x^2 + \Delta y^2) + p_2(\Delta D^2)\right] \rightarrow \min \quad (11)$$

where: $\Delta x, \Delta y$ are residual for the image coordinates, ΔD are residual for space distance and $[\ ]$ express total sum.

Weight values in equation (11) should be carefully considered under statistically or measurement accuracy, and calibration results were investigated using various weights. However, calibration results don't show any significant improvements compared with various weight values. Therefore, equal weight ($p_1 = p_2 = 1$) was adopted in this paper.

4. PERFORMANCE EVALUATION

In order to evaluate an accuracy of the IBIM, experiment was performed. Figure 5 shows test site, 20 circular points in Figure 5 are temporal GCPs and check points. A stereo image was taken with 21.790m (left side), 21.957m flying height (right side) respectively and 8.44m base line under the fixed focal length. The 3D coordinates for all circular points and space distances were measured by the first class motorized total station (distance accuracy: ±1mm, angle accuracy: ±2″).
Image coordinates for each point were given as the center of area gravity by image processing. Accuracy for 3D coordinates of check points was compared with space resection using 9 GCPs.

Figure 5. Test site

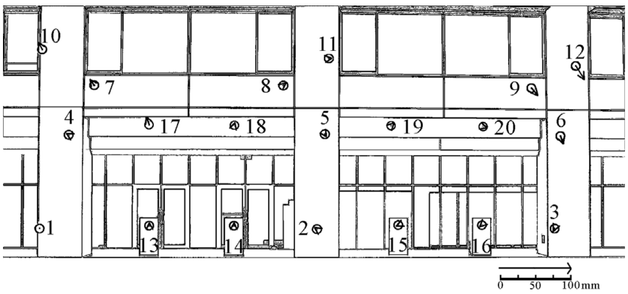

Figure 6. Error distribution (XY-plane)

In Figure 6, No. 1,3,10,11,12,14 points are temporal GCPs, and No. 1,3,10,11,12,14,15 are GCPs in the resection method. Therefore, No. 2,4,5,6,7,8,9,13,16 are common check points for the both method. Table 1 and 2 show calibration results. Table 3 shows the RMSE for XY and Z coordinates regarding check points.

Table 1: Calibration result of exterior orientation parameters

	Left	Right
X_0	2716.230 mm	11131.760 mm
Y_0	537.089 mm	533.492 mm
Z_0	20910.787 mm	20947.073 mm
ω	1° 31′ 49″	1° 40′ 45″
ϕ	11° 45′ 39″	-10° 54′ 51″
κ	-0° 03′ 10″	-0° 23′ 03″

Table 2: Calibration result of interior orientation parameters

x_0	1055.999 pixels	a_1	290.094
y_0	778.417 pixels	a_2	-0.007
f	7.223 mm	k_1	4.5518E-08

Table 3: The R.M.S.E. for XY, Z coordinates

	IBIM (New)	IBIM (Old)	Space resection
XY	9.560 mm	16.624 mm	5.204 mm
Z	6.453 mm	9.504 mm	9.388 mm

Form Table 3, it can be seen that the accuracy of Z coordinate shows better than the value that was computed space resection method using 9 GCPs and former method. Moreover, although the accuracy of XY coordinates shows lower value compare with space resection, it can be seen obviously that the accuracy of XY coordinate was improved compare with former method. Therefore, it is concluded that the new calibration method was effective method for the IBEM.

On the other hand, Figure 6 shows error distribution of XY coordinates (residual values of XY coordinates were enlarged 20 times). From Figure 6, it can be found that large error occurred on upper right points, in particular No. 12 shows large error.

As a reason, it may be supposed that the gap of the optical and laser axis or the imperfection of correction for lens distortion. These issues are further works. However, it is concluded that flexible 3D measurement is achieved by the IBIM. Since the IBIM doesn't need any surveying on an object field nor previous interior orientation procedures.

5. APPLICATION TO 3D MODELLING

3D modelling was investigated in this paper as one of applications of the IBIM System. Figure 7 shows over view of test site, and Figure 8 shows detail 3D model, which were created by general CG software. These 3D models were reconstructed using feature points, which were acquired by manual, and textures were taken by digital camera.

It can be said that these 3D models, which were reconstructed using the IBEM, have ability to apply for scene modelling in virtual environment.

Figure 7. Over view of test site

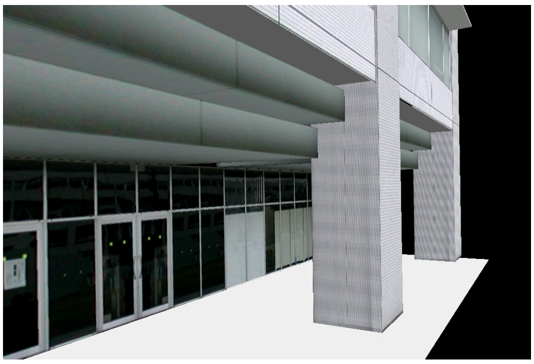

Figure 8. Detail of 3D model

6. CONCLUSION AND FURTHER WORK

The Image Based Integrated Measurement (IBIM) System, was developed by the authors for a convenient digital photogrammetry using digital cameras, and performance evaluation were investigated in this paper. 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. Moreover, the new calibration method using additional distance, which is computed, from measured distances between camera and temporal GCPs by this system, was verified as an effective method for accuracy improvement in the IBEM system.

On the other hand, it is expected that 3D models, which are reconstructed using the IBEM, have ability to apply for scene modelling in virtual environment.

However, newly issues, which need to be resolved before this system may become more operational, came up. These problems are more accuracy improvement, expansion of application field and acceleration of downsizing/handling.

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