MULTIPLE SENSOR MODELING OF DIFFERENT DIGITAL CAMERAS AND IMAGE BASED INTEGRATED MEASUREMENT SYSTEM FOR DIGITAL DOCUMENTATION OF CULTURAL ASSETS

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KEY WORDS: Digital cameras, Laser, Bundle adjustment, Measurement system, Cultural assets

ABSTRACT:

Convenient 3D measurements using consumer grade digital cameras are enormously expected in various fields with appearance of low coat and high-resolution digital cameras. In these circumstances, there are many 3D measurement applications. However, there are still problems for efficient digital photogrammetry. These problems include measurement of Ground Control Points for absolute orientation and interior orientation which should be performed beforehand, and these restrictions should be removed for ideal convenient photogrammetry using consumer grade digital cameras. With this objective, Image Based Integrated Measurement (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 or control points which have exact 3D coordinate in object field.
This paper focuses the IBIM system using triplet images of multiple digital cameras and its performance evaluations, and 3D modeling is discussed from the view point of non-contact measurement for cultural asset.

1. INTRODUCTION

Convenient 3D measurement using consumer grade digital camera is enormously expected in various fields with appearance of the low cost and high-resolution consumer grade digital cameras. In these circumstances, there are many 3D applications for digital photogrammetry on the market. However, these software requests Ground Control Points which have exact 3D coordinates for camera calibration or scale distance for absolute orientation or interior orientation parameters which should be acquired beforehand. These restrictions should be removed for ideal convenient photogrammetry using consumer grade digital cameras.
With this objective, Image Based Integrated Measurement system called as IBIM system was developed by the authors. The IBIM system consists of consumer grade digital camera and laser distance meter (Ohdake and Chikatsu, 2007). Furthermore, the IBIM system have function to rotate in vertically and horizontally so that the precise distances from centre of the camera to the feature points on object field can be measured, and the images are record on a SD memory card of the camera. The most remarkable point of the system was its ability to calculate both of the exterior and interior orientation parameters without scale distance nor GCPs in object field. There were still issues, however, as further work. These issues are labor and time consuming in distance measurement and deterioration of image quality. Identification for the same points and detection of occlusion area in measuring procedures at different camera positions are performed with labor and time consuming as manual task. In particular, deterioration of image quality is caused by half mirror, and the images in the IBIM system are taken through the half mirror. Therefore, deterioration of image quality was unavoidable problem.
In order to remove these issues and realize practical IBIM system, single image which is taken by the IBIM system and stereo image which is taken by the multiple digital cameras on both sides of the IBIM are fused. In this practical IBIM system, the distances are measured at only centre position. After triplet images are calibrated simultaneously, texture modelling is achieved using images which are taken by different digital camera on both sides of the IBIM. On the other hand, the additional remarkable point of the IBIM system is its ability to archive non-contact measurement.
After the practical IBIM system are evaluated, topographic surveying for a cliff where is requested non-contact measurement was performed using the practical IBIM system in this paper. It is concluded from the view point of non-contact measurement and practicability that the practical IBIM system is expected to become a useful system for the various close range application fields.

2. IBIM SYSTEM

The IBIM system consists of consumer grade 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 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 1. Appearance of the IBIM system

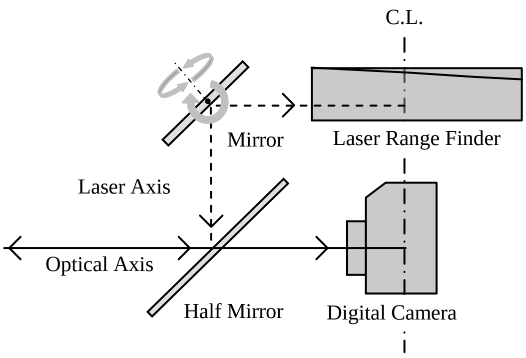


Figure 2. Configuration of the system

2.1 Issues of the IBIM system

The IBIM system had some issues in measurement procedures and the structural problems.

One issue is deterioration of image quality which is caused by taken through the half mirror of the IBIM system that is designed reflection of laser beam by laser distance meter. It is very important problem for practical IBIM system when image based stereo matching and 3D texture model.

Other issue is labor and time consuming in distance measurement which is influenced a result of camera calibration and accuracy of 3D-coordinates. Therefore, basic concept of the IBIM system has extended as follows.

i) First concept consists of 2 IBIM stations and stereo images using same control points.

ii) Second concept consists of 1 IBIM station and 2 images using C-770UZ outside of IBIM system or different digital cameras.

In order to investigate the practicability of the second concept using different digital camera for more conventional measurement, the IBIM system with new structure was developed by the authors.

2.2 IBIM system using Triplet Images

2.2.1 Initial Value of Pseudo GCPs: The IBIM system of former version computed initial value of pseudo GCPs with complicated processing using relative orientation and a distance of X-axis which is defined in local coordinate.

Initial value of pseudo GCPs were computed by distances from laser distance meter, image coordinates and focal length of nominal value. Figure 3 shows concept of pseudo GCPs

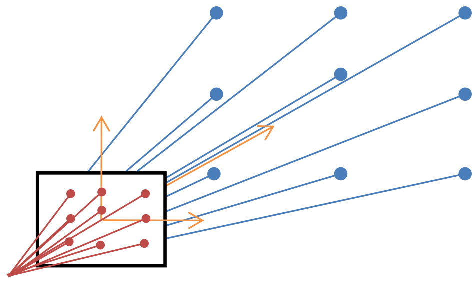


Figure 3. Concept of pseudo GCPs

Computation procedure of pseudo GCP is follows.

i) Transformations from the pixel coordinate into the image coordinate of centre image of IBIM station using Equation(1) (Faugeras & Toscani, 1987).

$$u = u_0 + ax + by \qquad v = v_0 + cy \tag{1}$$

where, u, v = pixel coordinate (pixel)
u_0, v_0 = principal point (pixel)
x,y = image coordinate (mm)
a, c = scale factor
b = shear factor

ii) Computation of angles from each axis to pseudo GCPs on the image from perspective centre of lens (Wolf, 1974).

$$\alpha = \tan^{-1}\left(\frac{x}{\sqrt{y^2+f^2}}\right) \qquad \beta = \tan^{-1}\left(\frac{y}{\sqrt{x^2+f^2}}\right) \qquad \gamma = \tan^{-1}\left(\frac{\sqrt{x^2+y^2}}{f}\right) \tag{2}$$

where, α, β, γ = angles from X, Y, Z axis

iii) Computation of pseudo GCP on ground coordinates which is the origin of centre camera.

$$X = D\cos(\alpha) \qquad Y = D\cos(\beta) \qquad Z = D\cos(\gamma) \tag{3}$$

Where, X, Y, Z = Initial pseudo GCP on ground coordinate.

iv) Transformations from the origin of centre camera into the origin of one pseudo GCP.

2.2.2 Multiple Sensor Modeling: In order to use multiple cameras, unknown parameters are 3 exterior parameters (X_0, Y_0, Z_0, ω, φ, κ) and 3 interior parameters {f (focal length), u_0, v_0 (principal points), a, b (scale factor, shear factor), k_1, k_2 (lens distortion)} and pseudo GCPs(X_i, Y_i, Z_i). Therefore, numbers of unknown parameters becomes 39+3n (n: numbers of pseudo 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 coordinates is given as P_1 (0, 0, 0) for origin point and X direction is given as P_2 (X_2, 0, 0) and fixing of rotation of X axis is given as P_3(X_3, Y_3, 0). Then, 39+3n-6 becomes unknown parameters against n (distances) + 3×2n (collinearity condition), at least 9 feature points as control points have to be measured by the laser distance meter mounted on the IBIM system at only centre station. These unknown parameters can be calculated as the values which make following function H minimum under least square method.

$$H = \sum_{i=1}^{m}\sum_{j=1}^{n}\left\{p_1\left(\Delta x_{ij}^2 + \Delta y_{ij}^2\right) + p_2\left(\Delta D_{ij}^2\right)\right\} \Rightarrow \min \qquad (4)$$

where, Δx, Δy = residuals for image coordinate
ΔD = residuals for distance
m = numbers of pseudo GCP
n = numbers of image
p_1, p_2 = weight

Here, collinearity condition is shown as equation (5), and distance condition is shown as equation (6).

$$x = -f\,\frac{m_{11}(X - X_0) + m_{12}(Y - Y_0) + m_{13}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)}$$
$$y = -f\,\frac{m_{21}(X - X_0) + m_{22}(Y - Y_0) + m_{23}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)} \qquad (5)$$

where, x, y = image coordinate
X_i, Y_i, Z_i = ground coordinate
X_0, Y_0, Z_0 = perspective centre
m_{11}-m_{33} = rotation matrix

$$D_i = \sqrt{(X_i - X_0)^2 + (Y_i - Y_0)^2 + (Z_i - Z_0)^2} \qquad (6)$$

where, D = distance from control point to perspective centre
Xi, Yi, Zi = ground control point coordinates
X_0, Y_0, Z_0 = perspective centre of centre position

Furthermore, radial polynomial 5th degree of equation (7) was adapted to correct lens distortion in this paper (Fryer J. G. and Brown D.C, 1986).

$$x = x' + \frac{x'}{r}\left(k_1 r^3 + k_2 r^5\right)$$
$$y = y' + \frac{y'}{r}\left(k_1 r^3 + k_2 r^5\right) \qquad (7)$$
$$r = \sqrt{x'^2 + y'^2}$$

Where, x, y = corrected image coordinates
x', y' = image coordinates
k_1, k_2 = coefficients of radial distortion
r = radial distance from principal points

3. PAFORMANCE EVALUATION

3.1 Indoor Experiment

Indoor experiment was performed using 3 consumer grade digital cameras. Table 1 shows specifications of digital cameras. Figure 4 shows test target (H:640mm, W:480mm, D:20mm(3 columns in the center)) which was used in this paper. The red circle points inside of thin line square are control points for camera calibration and 143 black circle points outside of thick line rectangle are check points. Each black circular point was manufactured with ±0.05mm accuracy, and pixel coordinates for these points were obtained as area gravity by image processing procedures.
5 triplet images for every camera were taken with changing altitude between 0.65-0.96 m so that uniform image scale be able to keep, and camera calibrations were performed by the simultaneous adjustment using 9 control points.
After the camera calibration, accuracy is estimated using RMS error for 143 check points.

Camera maker	Model name	Mega pixel	Focal length	Sensor type
OLYMPUS	C-770UZ	4.0	6.3 mm	1/2.5”
Sony	N1	8.0	7.9 mm	1/1.8”
Nikon	S600	10.0	5.0 mm	1/2.33”

Table 1. Specifications of digital cameras

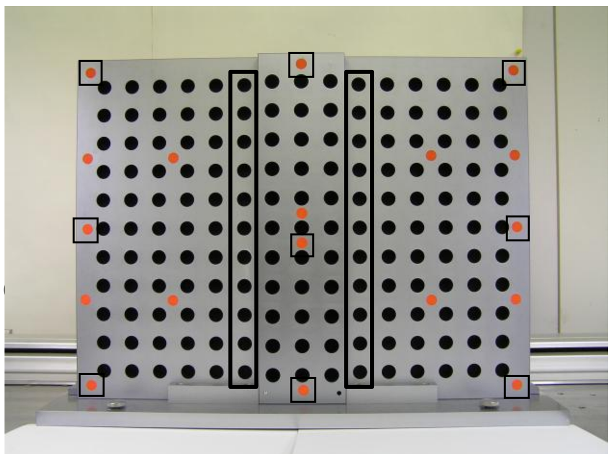


Figure 4. Test target

3.2 Accuracy

Table 2 shows root mean square error for 143 check points which is computed from equations(8). σ_{XY} mean horizontal error and σ_Z means vertical error. Standard error which is computed from equations (9)(Abdel-aziz, 1982).

Model	RMSE		Standard error	
	σ_{XY}	σ_Z	σ_{XY0}	σ_{Z0}
C-770UZ	0.553	0.362	0.382	1.588
N1	0.750	0.410	0.241	1.002
S600	0.525	0.818	0.224	0.930

Table 2. Accuracy of IBIM system Unit: mm

From Table 2, comparing horizontal and vertical values, vertical values are better than horizontal values. It is estimated that vertical coordinates of pseudo GCPs are constrained by measured distances from IBIM system.

$$\sigma_{XY} = \sqrt{\frac{\sum\left(\sigma_{Xi}^2 + \sigma_{Yi}^2\right)}{2n}} \quad (8)$$

$$\sigma_Z = \sqrt{\frac{\sum \sigma_{Zi}^2}{n}}$$

Where, σ_{XY}, σ_Z = RSM error of horizontal and vertical
σ_{Xi}, σ_{Yi}, σ_{Zi} = differences in X, Y, Z coordinates
n = numbers of check points

$$\sigma_{XY0} = \frac{H}{f}\sigma_p \quad (9)$$

$$\sigma_{Z0} = \sqrt{2}\,\frac{H}{f}\,\frac{H}{B}\,\sigma_p$$

Where, σ_{XY0}, σ_{Z0} = standard error
H = altitude
f = focal length
B = base line
σ_P = measurement accuracy (here, measurement accuracy is estimated 1.0 pixels)

In order to evaluate, proportional accuracy (PA) is computed using mean standard error which are computed using RMS error for 143 points and object field diameter (Fraser, 1987).

$$PA = \sigma_c / D$$

$$\sigma_c = \sqrt{(\sigma_X{}^2 + \sigma_Y{}^2 + \sigma_Z{}^2)/3} \quad (10)$$

$$D = \sqrt{DX^2 + DY^2 + DZ^2}$$

Where, σ_c = mean standard error
σ_X, σ_Y, σ_Z = RSM error of X, Y, Z coordinates
D = diagonal distance across the object field
DX, DY, DZ = distance object field

Figure 5 shows denominators of proportional accuracy. It can be said from figure 5 that IBIM system using triplet images which taken by multiple cameras has ability to obtain equivalent accuracy of standard error.

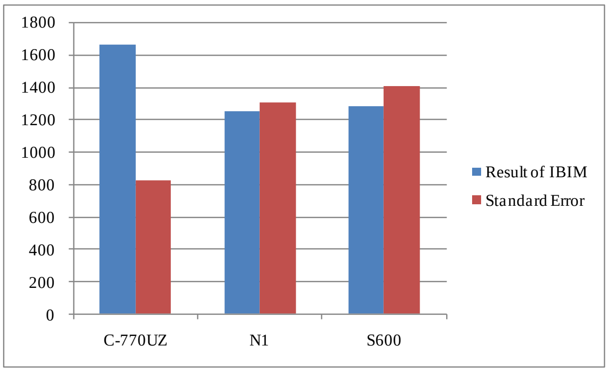


Figure 5. Denominators of proportional accuracy

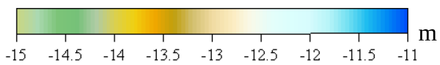
4. APPLICATION OF THE IBIM SYSTEM

4.1 CLIFF

In order to investigate evaluation and adaptability of the IBIM system to measuring and recording of complex geography, cliff (Figure 6) was measured by the IBIM system. 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)) about cross section. In addition, both the IBIM system and Terrestrial Laser Scanner were measured from distance (flying altitude) of 10m.

Figure 6. Appearance of the cliff

Figure 7-9 shows 3D model which were obtained by IBIM data and laser data respectively, and it can't find any significant differences between these 3D models. In order to evaluate more detail comparison, cross sections are investigated. Figure 10 and Figure 11 shows horizontal and vertical cross sections for the place where is shown in figure 7-9. Gray line (C-770UZ) and light gray line (C-770UZ and N1) shows cross section by IBIM system and black line shows laser surveying. Similarly, it can't find any significant differences between these cross sections.



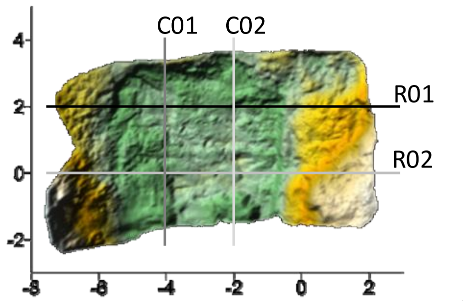


Figure 7. 3D model of the IBIM system using single camera(C-770UZ)

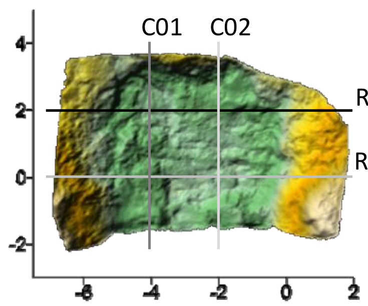


Figure 8. 3D model of the IBIM system using multiple cameras (C-770UZ and N1)

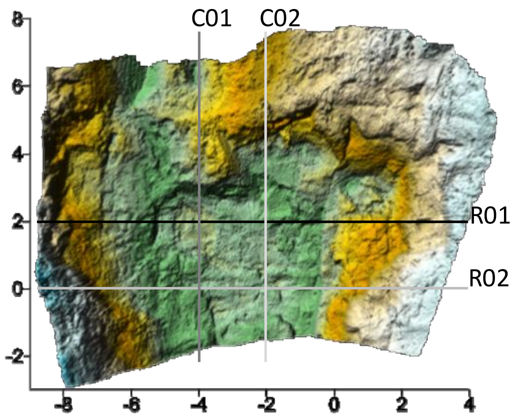


Figure 9. 3D model of Terrestrial Laser Scanner

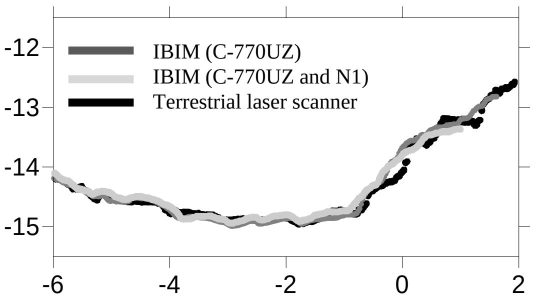


Figure 10 a. Cross section of R01

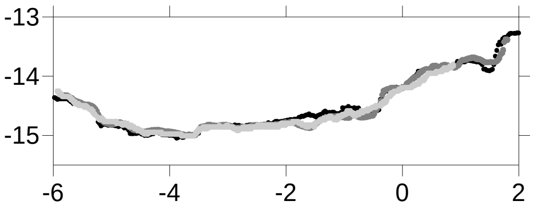


Figure 10 b. Cross section of R02

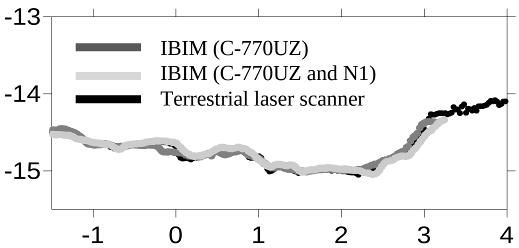


Figure 11 a. Cross section of C01

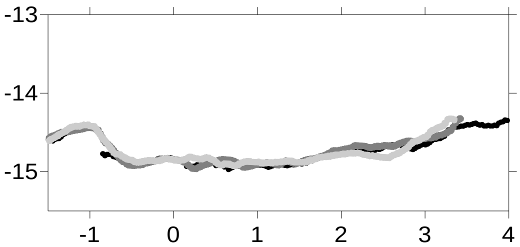


Figure 11 b. Cross section of C02

5. CONCLUSION

The Image Based Integrated Measurement (IBIM) System using multiple digital cameras and laser distance meter was developed by the authors for a convenient digital photogrammetry, and realization of practical the IBIM system was investigated in this paper.

Though, deterioration of image quality was unavoidable problem for the IBIM system since deterioration of image quality is caused by half-mirror. It is verified, however, deterioration of image quality is resolved by the Triplet IBIM system, which was proposed in this paper. In particular, as remarkable points for the Triplet method, multiple sensor fusion became possible since it is able to use other camera for left and right side camera. Similarly, it is verified that it can't find significant differences between accuracy for the IBIM system and Terrestrial Laser scanning.

Therefore, it is concluded that the practical IBIM system is accomplished by the Triplet method using different digital cameras, and the practical IBIM system is expected to become a useful measurement system for the various close range application fields (e.g. non-contact measurement for cultural assets) since interior orientation parameters and exterior orientation parameters are calibrated simultaneously without any scale distances nor GCPs on object field.

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