DEVELOPMENT OF HYBRID DIGITAL CAMERA FOR DIGITAL ARCHIVES OF HISTORICAL STRUCTURES

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ABSTRACT

A convenient 3D measurement using amateur digital camera is enormously expected from various fields according to appearance of the high resolution amateur cameras since pixel numbers of amateur digital cameras are amazingly increasing by modern semiconductor and digital technology. In these circumstances, software for low-cost digital photogrammery "3DiVision" was designed to perform convenient 3D measurement using 3 mega amateur digital cameras. However, there are issues for efficient digital photogrammetry using amateur digital camera. These problems are distance meas urement and previous interior orientation, and these restrict conditions should be removed for ideal convenient photogrammetry.
With this motive, Hybrid Digital Camera system was developed by the authors consisting of 5 parts: mirrors, amateur digital camera, laser profiler, personal compute and monitor. The most remarkable point of this system is its ability to calculate orientation parameters without scale distance or GCP on an object field. This paper describes a Hybrid Digital Camera system, and investigates an adaptability of this system to 3D modeling of historical structures in architecture and archaeology.

1. INTRODUCTION

Recently, pixel numbers of the amateur digital cameras are amazingly increasing by modern semiconductor and digital technology, and there are many amateur digital cameras which have more than 3 mega pixels on the market in Japan. For example, 69 kinds of digital camera which have more than 3 mega pixels are on the market at the 5th of March 2003, and 25 million digital cameras were shipped in 2002. Instead of film camera was 2.2 million. Furthermore, functionary of transmission was standardized. Figure 1 shows sharp rise in pixel numbers for the amateur digital cameras.

In these circumstances, a convenient 3D measurement using amateur digital camera is enormously expected from various fields. In particular, developing a low-cost photogrammetric system using armature digital camera is one of the important issues for the ISPRS WG V/4 (Image Analysis and Spatial Information Systems for Applications in Cultural Heritage). Similarly, efficient construction of digital archives or virtual environments for structures of architectural significance and objects of importance to the cultural heritages have recently received more attention.

With this motive, performance evaluations for the amateur digital cameras were investigated by the authors from the view point of digital Photogrammetry (Kunii & Chikatsu, 2001(a)), and it was concluded that 3 mega amateur cameras are enormously expected to become useful tool for convenient digital photogrammetry since it can be seen in Figure 2 that accuracy for more than 3 mega amateur cameras are hardly varied (Kunii & Chikatsu, 2001(b)).

Therefore, the authors have been concentrating on developing a convenient 3D measurement using 3 mega amateur digital cameras, and software "3DiVision" was designed to perform convenient 3D measurements (Chikatsu & Kunii 2002). Application of 3DiVision to 3D modeling of historical object was also performed (Nakada & Chikatsu 2003). However, there are some issues for practical 3D measurements using amateur camera. These problems are distance measurement for giving scale in absolute orientation and previous interior orientation.

In order to remove these restrict condition and to promote a convenient digital photogrammetry using amateur digital camera, Hybrid Digital Camera (HDC) system was developed by the authors consists of 5 parts: mirrors, digital camera, laser profiler, personal compute and monitor. The most remarkable point of this HDC is its ability to calculate both exterior and interior orientation parameters simultaneously without scale distance or GCP. After describing the HDC, an adaptability of this system to 3D measurement of a historical object in architecture and archeology is investigated in this paper.

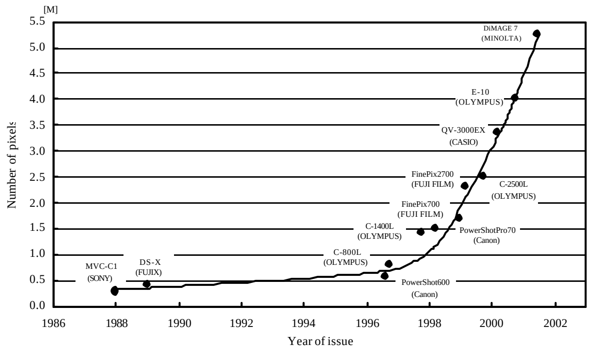

Figure 1. Sharp rise in resolution of amateur digital camera.

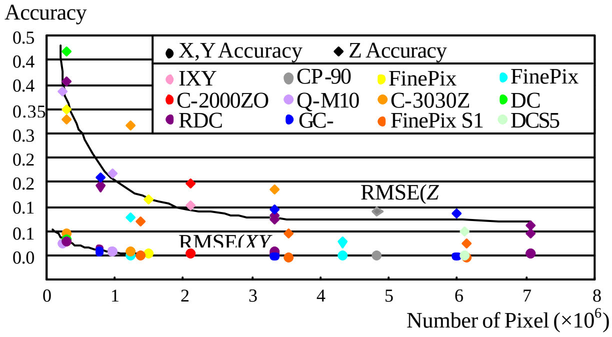

Figure 2. Relationship between accuracy and pixel numbers

2. 3 DiVison

"3DiVision" under the key words; 3Dimension, Digital image and Visualization was designed to perform convenient 3D measurement using amateur digital camera (Chikatsu & Kunii 2002). The main algorithm of the 3DiVision is simultaneous adjustment using left and light image under combination with coplanarity condition and bundle adjustment, and 3DiVision have capability to perform orientation (interior, exterior) and 3D measurement. For example, there are no restrictions for imaging, and exterior orientation parameters are computed using scale distance *D* and interior orientation parameters (Figure 3). Therefore, it was concluded that 3DiVision is useful software, but in order to remove scale distance and previous interior orientation, and to promote a convenient 3D measurement using amateur digital camera, Hybrid Digital Camera (HDC) system was developed.

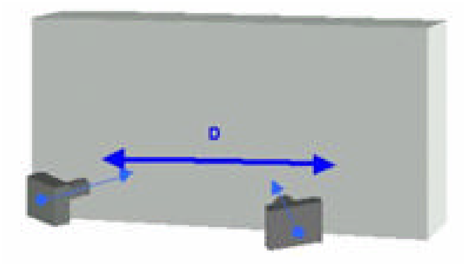

Figure 3. Concept of 3DiVidion

3. HYBRID DIGITAL CAMERA

3.1 Outline of HDC

HDC consists of 5 parts: mirrors, digital camera, laser profiler, personal compute and monitor.
The details for each part are as follows:

・**Mirrors**
+ Axes for a camera and Laser profiler are adjusted by mirrors.
・**Camera**
+ OLYMPUS C-3040 (3.14 mega pixels)
・**Laser profiler**
+ Leica LDS-1(accuracy is ±3mm to 40m)
・**PC**
+ Pentium, 850Hz
+ Digital camera and laser profiler are controlled via PC.
+ Image and distance data are recorded on PC.
・**Monitor**
+ 6.4 inch display is used as a finder and PC monitor.

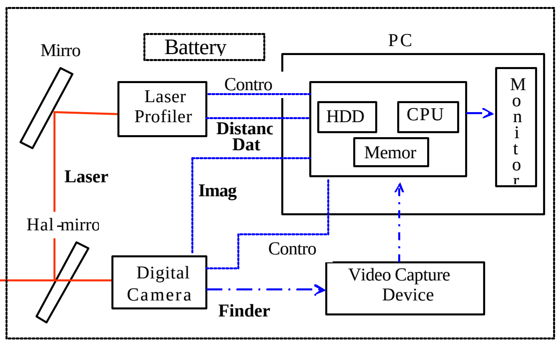

Figure 4. Configuration of HDC

Figure 5. Appearance of the HDC

On the other hand, the HDC is able to rotate in vertically and horizontally so that precise distance can be measured, and battery and video capture device are also equipped. Figure 4 shows the configuration and Figure 5 shows the appearance.

3.2 Camera Calibration

In order to perform camera calibration, at least 6 distances for the points which show feature on an object field from the center of the camera have to be measured by 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}, $?_L$, f_L, $?_L$), (X_{OR}, Y_{OR}, Z_{OR}, $?_R$, f_R, $?_R$)}, interior orientation parameters {*f* (focal length), x_0, y_0 (principal points), a_1, a_2, (scale factor), p_1 (lens distortion)} and 3D coordinates for the 6 temporal GCPs should be calculated. However, X or Y axis and 2 points which have the same height value or height values for 2 points are required to prevent rotations. Furthermore, let select original point and the point which define the X-axis direction in temporal GCPs, and assume 3D coordinates for the original point are (0,0,0), 3D coordinate for the point can be assumed as (X,0,Z). Therefore, 30 parameters become unknown.

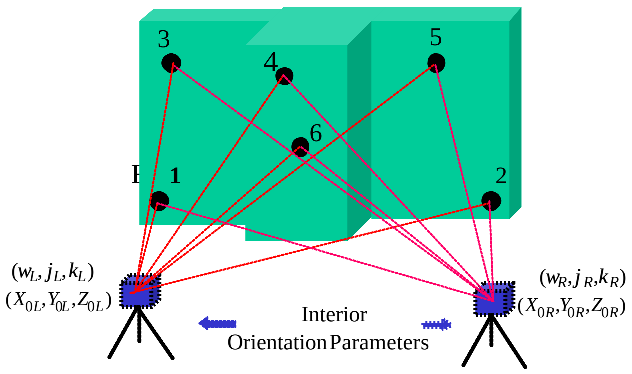

Figure 6. Measurement procedures

Figure 6 shows concept of measurement by the HDC, and measurement procedures are as follows:
+ After imaging at left position, distances for the 6 temporal GCPs are measured by rotating the HDC.
+ Repeat same procedures at right position.
+ Acquisition of image coordinates for the 6 temporal GCPs and additional feature points for 3D measurement.

On the other hand, 36 observation equations are obtained from 24 collinearity conditions and 12 distance conditions. Therefore, 30 unknowns are computed as the values which makes following function G minimum under least square method. Furthermore, 3D coordinate for additional feature points are able to compute simultaneously.

$$G = \{[p_1(\Delta x_i^2 + \Delta y_i^2)] + [p_2(\Delta L_{ij}^2)] + [p_3(\Delta X_i^2 + \Delta Y_i^2 + \Delta Z_i^2)]\} \rightarrow min \qquad (1)$$

where: p: weight, $?x$, $?y$: residual for image coordinate, $?L$: residual for distance, $?X$, $?Y$, $?Z$: residual for 3D coordinates of the temporal GCP.

The detail calibration procedures are follows:
+ Performance of relative orientation using temporal GCPs.
+ Calculation of approximate scale.
+ Calculation of approximate 3D coordinates using the scale.
+ Simultaneous adjustment by function (1).

In the calibration procedures, approximate scale is obtained as ratio for AB/ab in Figure 7.

Where,

$$ab = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2}$$

$$AB = \sqrt{OA^2 + OB^2 - 2 \cdot OA \cdot OB \cdot \cos a}$$

$$\cos a = (x_a \cdot x_b + y_a \cdot y_b + f^2) / Oa \cdot Ob$$

$$Oa = \sqrt{x_a^2 + y_a^2 + f^2}, Ob = \sqrt{x_b^2 + y_b^2 + f^2}$$

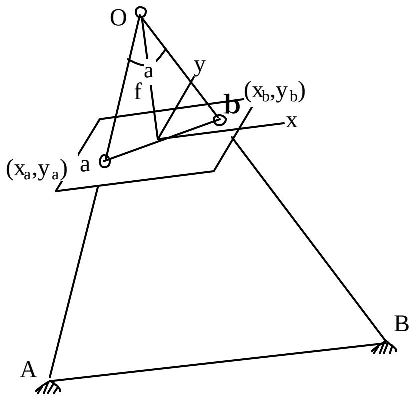

Figure 7. Calculation of approximate scale

3.3 Accuracy Evaluation of HDC

In order to evaluate an accuracy of the HDC, the center of each black circle point on the test target (Figure 8) were measured by motorized total station (SOKKIA MET2NV, distance accuracy ±1mm, angle accuracy ±2″). Figure 9 shows a magnified circle target. Stereo image was taken with 3.546m and 3.542m altitude respectively and 1.19m base line under focal length was fixed.
An image coordinates for each point was given as a center of area gravity by image processing. Table 1 shows the RMSE for XY and Z coordinate for 42 check points. X or Y given means that X or Y axis was given respectively, and RMSE with 9 GCPs show the result of the bundle adjustment using 9 control points. Table 2 shows calibration results.

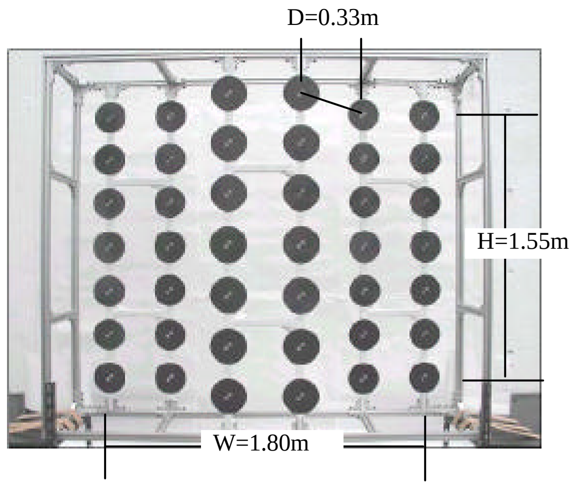

Figure 8. Test target

Figure 9. Magnified circle point

It can be said that both X axis was given and Y axis was given are the same accuracy. Although, both accuracies are lower 2 or 3 times compare with the result of bundle adjustment, but it is supposed that were caused by imperfection of axis for the camera and laser profiler. Furthermore, because of this HDC doesn't need any surveying on an object field nor previous interior orientation procedure. Therefore, it is concluded that flexible 3D measurement is achieved by the HDC.

Table 1. RMSE for the check points

		XY	Z
RMSE	X:given	1.204mm	2.283mm
	Y:given	1.127	2.278
RMSE with 9GCPs		0.427mm	1.012mm

Table 2. Orientation parameters

		ω φ κ	X_O Y_O Z_O	x_0 y_0 f	a_1 a_2 p_1
X:given	Left	-0° 8′ 28.5″ 0 40 44.7 -0 4 41.3	139.618mm 568.589 3,540.265	1,020.763 pix 729.808 pix 7.262mm	289.326 -0.388 0.347×10-7
	Right	-0 14 28.2 0 21 12.1 -0 3 38.2	1,324.770 565.293 3,537.574		
Y:given	Left	-0° 8′ 28.6″ 0 40 44.8 -0 5 42.1	139.449mm 568.631 3,540.265	1,020.763 pix 729.809 pix 7.262mm	289.327 -0.388 0.347×10-7
	Right	-0 14 28.3 0 21 12.1 -0 4 39.0	1,324.604 565.685 3,537.574		

4. 3D MODELING

4.1 Data acquisition

3D modeling for the "Koma house" was performed in this paper as an application of the HDC system. The Koma house was built in 17th century (300 years ago), and designated as national important cultural assets in 1971. Due to restriction of imaging, 2 Stereo pairs only for the front and left side were taken using the HDC system, and stereo pairs for the other sides were taken by digital camera (EPSON CP-900Z) with wide angle lens (Figure 10).

The major detail procedures for data acquisition are as follows:
+ After the camera calibration for the HDC, feature points were extracted by semi-automatic.
+ Calculation of 3D coordinates for the extracted points.
+ Relative orientation for each stereo pair which was taken by the digital camera was performed by coplanarity condition.
+ Absolute and successive orientation for each pair were performed using 3D data which were obtained from the HDC system.

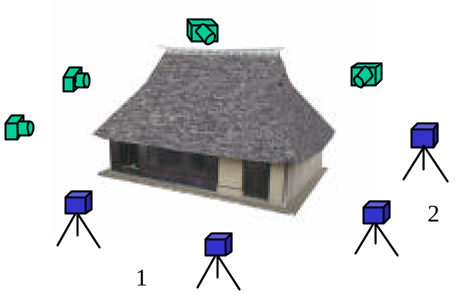

Figure 10. Stereo pairs for the Koma house

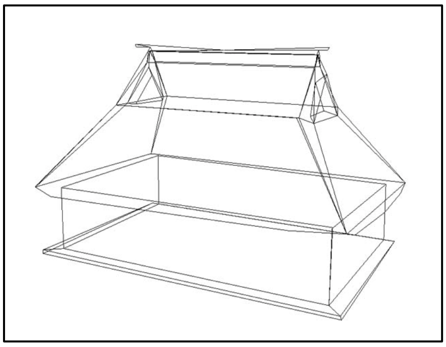

Figure 11. Wire frame model

Figure 12. 3D texture model

4.2 Modeling

Efficient modeling system is still developing; however basic modeling procedures are as follows;
+ Generating polygons using extracted feature points.
+ Cut textures for the polygons from the images.
+ Textures are mapped to polygons on the wire frame model.

Figure 11 shows reconstructed wire frame model, and Figure 12 shows the 3D texture model.

5. CONCLUSION AND FURTHER WORK

The Hybrid Digital Camera (HDC) System was developed by the authors for a convenient digital photogrammetry, and it is concluded from the accuracy evaluation that the HDC system is expected to become a useful system in the various application fields since both exterior and interior orientation parameters are calibrated simultaneously without any scale distance nor GCP on the object fields. In particular, the remarkable point of this HDC is its ability to realize on site camera calibration.
The adaptability of the HDC to 3D modeling of the historical object was investigated. However, investigation has come up with some issues which need to be resolved before this system may become more operational. These problems are improvement over imperfection of the axis for the camera and laser profiler, acceleration of downsizing and construction of efficient 3D modeling system.

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