Lens Calibration for Digital Photogrammetry and the Application

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***ABSTRACT*:** A specification of a digital camera is improving rapidly. High grade digital camera such as single lens reflex camera has over 10M pixel in a CCD. Then the accuracy of an angle measurement can achieves less than 1 second (1/3600 degree). This is almost the same specification with surveying equipment such as total station or transit. When stereo imageries are obtained, 3 dimensional measurement can be carried out base on co-linearity equation with ground control points. The ground control point means known 3 dimensional coordinates on the imagery. At least 4 ground control points are required to derive co-linearity equation. Moreover, lens distortion must be eliminated for accurate measurement. The elimination of the lens distortion is called lens calibration. Usually, the lens calibration is very difficult because many ground control points must be prepared. For easy lens calibration, the authors suggests a method using constellation pictures. Stars are accurately measured in this method. Starcatalogue has information of dimensional coordinates with some parameters. And the stars are too far from the earth. Then, the distance between the stars and the earth assumed infinite. Therefore, the position and attitude of camera in the constellation pictures also assumed center of celestial sphere. Computation of parameter of lens distortion will be very simple. After lens calibration, 3 dimensional measurement using digital camera can be carried out. Advantages of digital photogrammetry is high resolution 3 dimensional data can be obtained. The digital photogrammetry will be applied in some fields such as measurement of disaster site, an archive of surface model. This paper reports suggested method of lens calibration. Moreover, applications of digital photogrammetry are presented.

***KEYWORDS*:** lens calibration, digital photogrammetry, application

1. Introduction

A specification of a digital camera is improving rapidly. High grade digital camera such as single lens reflex camera has over 10M pixel in a CCD. Then the accuracy of an angle measurement can achieves less than 1 second (1/3600 degree). This is enough accuracy for 3 dimensional measurement. The 3 dimensional measurement can be carried out base on co-linearity equation with ground control points. However, lens calibration is necessary for accurate measurement. The lens calibration is obtained highly accurate value of focal length, lens distortion, principal point position, and size of the surface of projection. The lens calibration is indispensable for measurement with a digital camera. Usually, many ground control points are necessary for lens calibration. The ground control point requires less than 1mm accuracy. On the other hand, the spatial distribution of ground control point is important. Thus, the lens calibration is very difficult. The author suggests using the constellation photograph as an easy lens calibration method. Stars are accurately measured in 0.1 seconds. The stars are so far from the earth that the position and attitude of the camera can be assumed to the center of celestial sphere. As a result, computation of parameter of lens distortion will be very simple. After lens calibration, 3 dimensional measurement using digital camera can be carried out. The digital photogrammetry will be applied in some fields such as measurement of disaster site, remain, and building, an archive of surface model. This paper suggested method of lens calibration and some application for digital photogrammetry.

2. Used camera

In this study, the digital camera D100 produced by Nikon was used. A lens calibrated digital camera is used. Table 2.1 shows calibration result by surveying company.

Table 2.1 Lens calibration result by TOPCON

Focal length	f [mm]	34.384595
X of principal point position	Xp [mm]	11.960479
Y of principal point position	Yp [mm]	7.833946
Distortion parameter	k1	1.274541E-05
	k2	-1.772969E-07
	p1	1.225290E-06
	p2	7.596063E-07
Resolution	[mm/pixel]	0.0079

3. Lens calibration

3-1. Used constellation picture

The constellation photograph taken in Kochi University of Technology on May 13, 2009 is used. Figure 3.1 shows constellation photograph. A yellow marker shows position of control points. The number of control points were 50. The white line shows the 7 stars in Big Dipper.

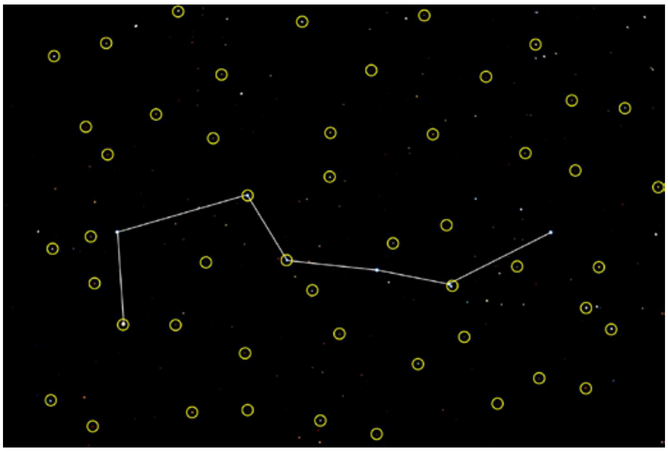

Figure 3.1 Constellation photograph

3-2. Calculation of star position

The stars are accurately measured. The positional information of the star was described in the Star Catalog. It is included their proper motion and annual parallax, etc. The proper motion and the parallax angle grow near the earth. Therefore, it is necessary to choose the far star from the earth. The stars are too far from the earth that the distance between the stars and the earth assumed infinite. Therefore, the position and attitude of camera in the constellation pictures also assumed the center of celestial sphere. The calculation of the star position used the correction expression 2). The proper motion, precession, nutation, annual parallax, and annual aberration can be calculated. Next, the right ascension and declination in the polar coordinate are calculated. Finally, the coordinates converted into the rectangular coordinates.

3-3. Lens distortion

The distortion exists in the lens. Therefore, it is necessary to correct the lens distortion. The lens distortion is corrected by the next expression.

$$\Delta u = \bar{u}(k_1 r^2 + k_2 r^4) + p_1(r^2 + 2\bar{u}^2) + 2p_2\bar{u}\bar{v}$$
$$\Delta v = \bar{v}(k_1 r^2 + k_2 r^4) + 2p_1\bar{u}\bar{v} + p_2(r^2 + 2\bar{v}^2) \tag{3.1}$$
$$\bar{u} = u - u_0$$
$$\bar{v} = v - v_0$$
$$r^2 = \bar{u}^2 + \bar{v}^2$$

$\Delta u.\Delta v$: *Calibration value of lens distortion*

u_0, v_0 : *Principal point position*

k_1, k_2, p_1, p_2 : *Distortion parameter*

3-4. 3 dimensional projection

The 3 dimensional projection of general calibration method was used for the calibration. The 3 dimensional projection is condense expression of co-linearity equation. The unknown coefficient of the 3 dimensional projection is calculates by the least squares method. In this study, the position of camera in the constellation pictures also assumed center of celestial sphere. The 3 dimensional projection can mathematic expression as follows.

$$u + \Delta u = \frac{b_1 X + b_2 Y + b_3 Z}{b_9 X + b_{10} Y + b_{11} Z}$$
$$v + \Delta v = \frac{b_5 X + b_6 Y + b_7 Z}{b_9 X + b_{10} Y + b_{11} Z} \tag{3.2}$$

b_i : *Unknown coefficient*

u, v : *Camera Coordinates of Target*

X, Y, Z : *Grouund coordinates of target*

$\Delta u, .\Delta v$: *Calibration value of lens distortion*

3-5. Calibration results

Positional error of lens distortion was calculated by unknown coefficient of 3 dimensional projection. Figure 3.2 shows positional error of lens distortion.

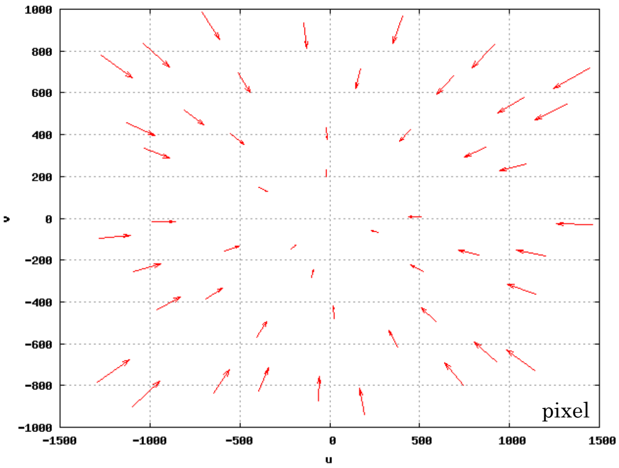

Figure 3.2 Positional error of lens distortion

Table 3.1 shows RMSE of positional error.

Table 3.1 RMSE of positional error

	[mm]	[pixel]
u	0.894	113.417
v	0.617	78.289

This time, the positional error of lens distortion was calculated by simplified the 3 dimensional projection. It will be necessary to review the simplification of the 3 dimensional projection in a future study.

4. Application of digital photogrammetry

Results of digital photogrammetry application are introduce in this section. Results are come from data composite of laser scanner data and digital camera image and an archive of surface model.

4-1. Compositing laser scanner data and digital camera image

The laser scanner can acquire 3D coordinates, intensity of refrectance and color image. However, color image is not enough quantities in the dark area data, because the laser scanner scans the object at high speed. Figure 4.1 shows a intensity of refrectance of laser scanner data inside the room.

Figure 4.2 shows a true color image of laser scanner data inside the room. It is unsuitable for the acquisition of the true color image in a dark area such as inside or apartment the room.

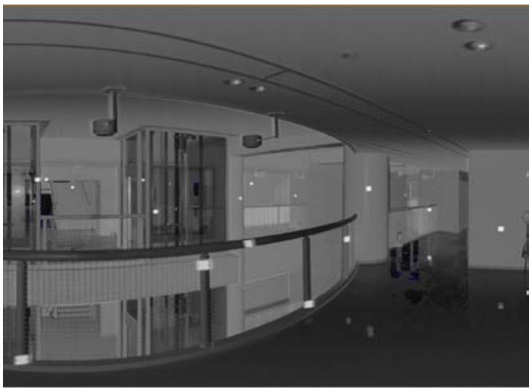

Figure 4.1 Grey scale

Figure 4.2 True color image

On the other hand, the digital camera can acquire clear color data inside the room. Therefore, the digital camera image can support color information of dark area for the laser scanner. A composite method of laser scanner and digital camera image is developed. As a result, the data in a room with dark area can be taken for the laser scanner.

4-1-1.Used Laser scanner

In this study, the laser scanner LMS-Z210 produced by Riegl was used. Table 4.1 shows performances of measurement distance. Table 4.2 shows specification of laser scanner.

Table 4.1 Performances of measurement

Range	≦350m
Shortest Distance	2m
Measurement Accuracy	±2.5cm (Standard Deviation)

Table 4.2 Specification of laser scanner

	Frame scan	Line scan
Pixek(max)	1160pixel	4621pixel
Angle Range	±40°	0～333°
Angle Resolution	0.036	0.018°

4-1-2.Geometry of laser scanner

The laser scanner can acquire highly accurate and high density 3 dimensional coordinate data in a short time. Figure 4.3 shows a basic concept of a laser scanner.

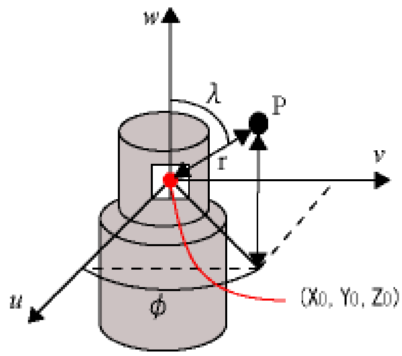

Figure 4.3 Basic concept of laser scanner

The acquired data of laser scanner had it own coordinate system. Therefore, geometric transformation is necessary. The geometric transformation used a 3D affine transformation. The 3D affine-transformation is shown in the next expression.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} p_1 & p_2 & p_3 \\ p_4 & p_5 & p_6 \\ p_7 & p_8 & p_9 \end{pmatrix} \begin{pmatrix} u \\ v \\ w \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix} \qquad (4.1)$$

p_i : *Parameter of transform*

X_0, Y_0, Z_0 : *Coordinate of laser scanner point*

u, v, w : *Ground coordinates of targe(The laser scanner system)*

X, Y, Z : *Ground coordinates of targe (The ground coordinate system)*

The unknown coefficient of 3D affine transformation are calculates by the least squares method with ground control points data.

4-1-3.Geometry of digital camera

Geometry of the digital camera is based on a co-linearity equation. The co-linearity equation is shown in the mathematic expression as follows.

$$u=-c\frac{u_p}{w_p}=-c\frac{a_{11}(X_p-X_1)+a_{12}(Y_p-Y_1)+a_{13}(Z_p-Z_1)}{a_{31}(X_p-X_1)+a_{32}(Y_p-Y_1)+b_{33}(Z_p-Z_1)} \tag{4.2}$$

$$v=-c\frac{v_p}{w_p}=-c\frac{a_{21}(X_p-X_1)+a_{22}(Y_p-Y_1)+a_{23}(Z_p-Z_1)}{a_{31}(X_p-X_1)+a_{32}(Y_p-Y_1)+a_{33}(Z_p-Z_1)}$$

c : *Focal lenght*
a_{ij} : *Element of Rotation Matrix* (ω,ϕ,κ)
X_1,Y_1,Z_1 : *Coordinate of camera position*
X_p,Y_p,Z_p : *Ground coordinates of target*
u,v : *Photographic coordinates of target*

The properties of co-linearity condition are object, center of surface of projection, and photograph image and they are exist on a straight line. Figure 4.4 shows a basic concept of co-linearity equation.

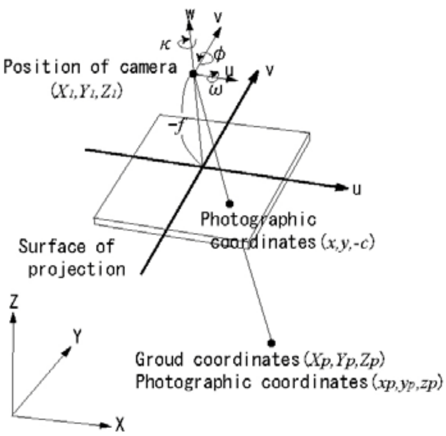

Figure 4.4 Basic concept of co-linearity equation

The relation between ground coordinates and image coordinates can be calculated according to the position (X_1,Y_1,Z_1) and attitude (ω,φ,κ) of the camera. They can be calculated by using coordinates of the ground control point. This calculation is called orientation.

4-1-4.Laboratory experiment

The test area is Kochi University of Technology. Figure4.4 shows an experiment situation.

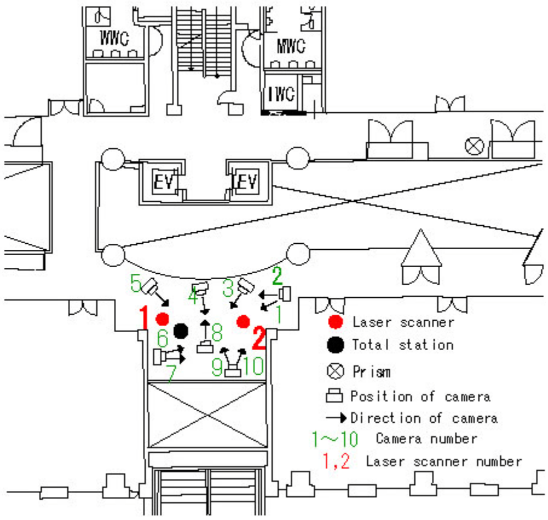

Figure 4.5 Experiment situation

In this laboratory experiment, the reflector sheet was used as a control point. The number of control point is 50. 360° data was acquired with the digital camera and laser scanner. Figure 4.6 shows an example of the digital camera image. A red marker shows position of the control points.

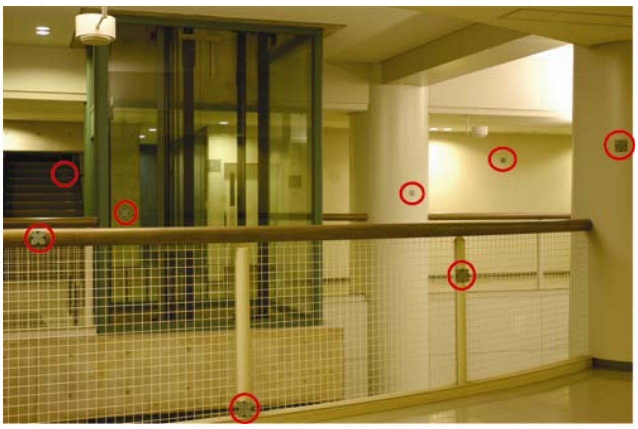

Figure 4.6 Digital camera image

4-1-5. Result of composite

The laser scanner data and the digital camera image were composited by original program which come with hardware. A bird's-eye view was made by using composite data. Figure 4.7 shows a bird's-eye view.

Figure 4.7 Bird's-eye view

The laser scanner data and the digital camera image were able to be composited. There is a problem of acquiring color information by mistake, if the image coordinates are the same. It will be necessary to solve this problem in a future study.

5. Reference

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