14 th Congress of the International Society of Photogrammetry

Hamburg 1980

Commission V

Working Group 5

Presented Paper

Shunji Murai, Hideshi Nakamura
Institute of Industrial Science
University of Tokyo

and

Yoshiro Suzuki
Department of Civil Engineering
Nippon University

Analytical Orientation for Non-metric Camera in the Application Terrestrial Photogrammetry

Analytical Orientation for Non-metric Camera in the Application to Terrestrial Photogrammetry

Shunji Murai, Hideshi Nakamura
Institute of Industrial Science
University of Tokyo

and

Yoshiro Suzuki
Department of Civil Engineering
Nippon University
Tokyo, Japan

ABSTRACT

The study deals with a comparative study on the performance of non-metric cameras (35mm film camera; Olympus f=50mm, Nikon f=50mm, 55mm, 70mm film camera; Hasselblad f=40mm, 80mm, 250mm) in the analytical orientation together with self calibration for (xp, yp), f and lense distortion. Examples of the application to the terrestrial photograpmmetry for the test site and for the site of mine excavation are shown.

As the results from the study, it is concluded that non-metric camera can be utilized for three dimensional measurement with almost same accuracy as that of metric camera, when three dimensionally located control points will be available.

INTRODUCTION

The objective of the study is to accomplish a feasible study on performance of non-metric camera in the application of three dimensional measurement to terrestrial photogrammetry.

In order to fulfill this objective, the following tests with respect to accuracy were executed.

1) Influence of difference of camera
2) Influence of interior orientation parameters
3) Influence of base length
4) Influence of difference of orientation method between collinearity equation and coplanarity equation

TEST CASES

a. Camera and film

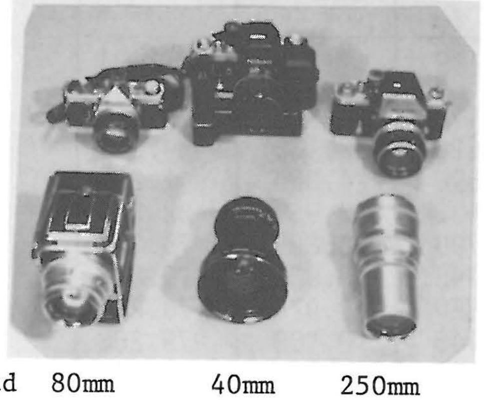
Three types of 35mm camera and a 70mm camera with three different lenses were tested as shown in Table 1. Panchromatic film, Fuji Neopan SS was utilized.

Observation to determine photographic coordinates was executed on the negative films. Fig. 1 shows these camera and lenses tested in the study.

Table 1 Camera, Lense and Image Format

CAMERA	LENS	IMAGE FORMAT
OLYMPUS M1	ZUIKO 50 mm F1.3	36 x 24 mm
NIKON F2	MICRO NIKKOR 55 mm F3.5	
NIKON F	NIKKOR 50 mm F1.4	
HASSELBLAD 500EL	PLANAR 80 mm F2.3	55 x 55 mm
	DISTAGON 40 mm F4	
	SONNAR 250 mm F5.6	

Olympus Nikon F2 Nikon F



Hasselblad 80mm 40mm 250mm

Fig. 1 Tested Camera and Lense

b. Test site

The building of the Institute of Industrial Science, University of Tokyo was selected as the test site. Sixteen control points were established on the walls as shown in Fig. 2. The distance to the nearest control point is about 32 meters and to the farthest control point is about 95 meters.

Table 2 shows coordinates of the control points. Point No. 11 was not available because of error. X axis was chosen as the direction of the base of the platforms, Y axis as the vertical direction, and Z axis as the direction of horizontal distance.

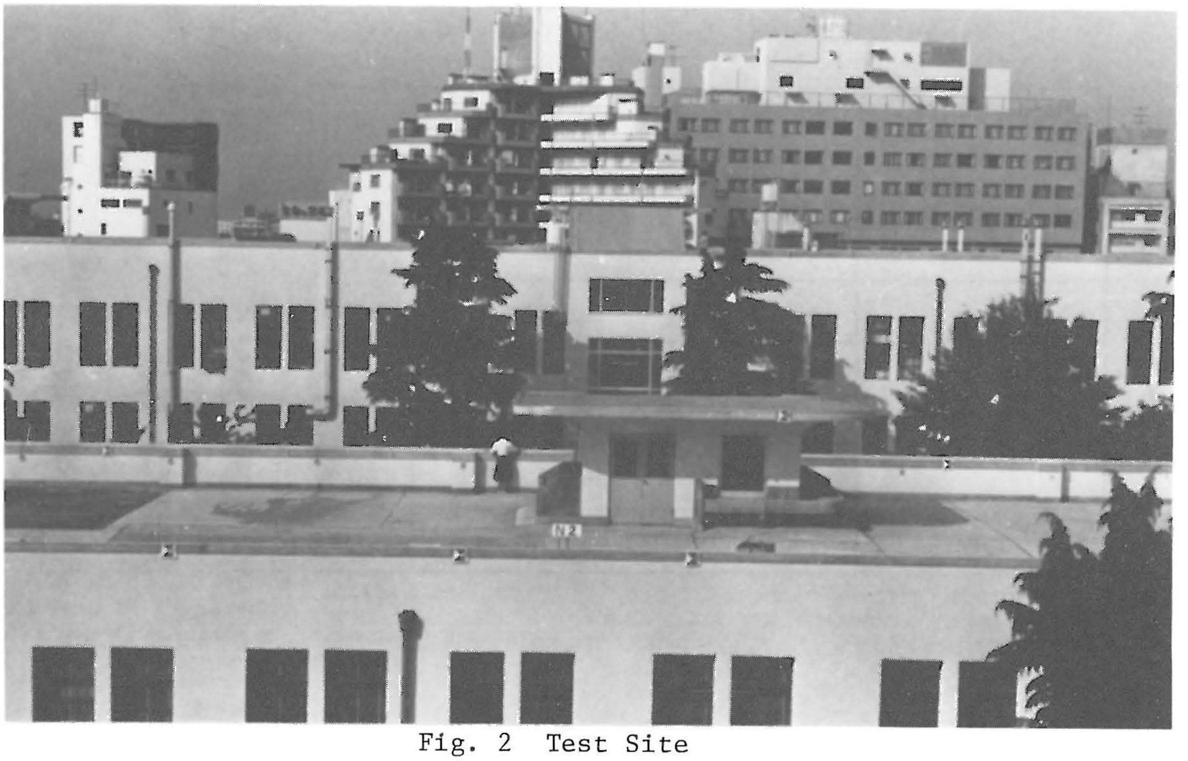


Fig. 2 Test Site

Table 2 Coordinates of Control Points

(Unit : meter)

NO.	X	Y	Z
1	15.798	-3.972	-32.261
2	20.583	-3.968	-32.257
3	11.412	-4.012	-47.257
4	26.686	-2.185	-39.320
5	31.590	-4.009	-47.265
6	24.432	-3.969	-32.251
7	2.799	0.899	-79.267
8	12.445	0.922	-79.267
9	21.860	0.925	-79.273
10	31.445	0.900	-79.268
11*	40.760	2.027	-78.981
12	27.829	2.615	-82.757
13	21.994	2.629	-82.740
14	13.393	1.874	-94.757
15	21.197	-13.818	-32.103
16	2.026	-14.582	-32.128

* Not available because of error

c. Stations and films

Three stations at the intervals of six meters were set up. 26 photographs were taken almost perpendicular to the base, that is, X axis, except a few represented by symbol of * in Table 3, which were taken a little convergent by supporting camera by hands.

In the case when base length is six meters, that is, the distance between O_1 and O_2, B/H ratio ranges 1:5.3 to 1:15.8.

In the case when base length is twelve meters, that is, the distance between O_1 and O_2, B/H ratio ranges 1:2.6 to 1:7.9.

Table 3 Stations and Films

Film	Camera	Station	Distance from O_1
1	Olympus	O_1	0meter
2		O_2	6
3		O_3	12
4		O_3*	12
5		O_1*	0
6	Nikon F2	O_1	0
7		O_2	6
8		O_3	12
9		O_3*	12
10		O_1*	0
11	Nikon F	O_1	0
12		O_2	6
13		O_3	12
14		O_3*	12
15	Hasselled Normal	O_1	0
16		O_2	6
17		O_3	12
18		O_1*	0
19		O_3*	12
20	Wide	O_1	0
21		O_3	12
22	Telescope	O_1	0
23		O_2	6

* supported by hands

d. Orientation parameters

The following four cases were tested, as shown in Table 4.

Case 1: Six exterior orientation parameters are determined for each single photograph, by applying least square method to Equation (1). Photographic coordinates are determined by measuring two points on each side of image format as shown in Fig. 3, and by applying least square method to affine transform.

Case 2: Twelve exterior orientation parameters for a pair of stereo photographs are determined, by adding coplanarity equation, as shown in Equation (2) to Equation (1).

Case 3: Six exterior orientation parameters and three interior orientation parameters of principal point (xp,yp) and focal length f are determined. (See Equation (3))

Case 4: Two more interior parameters of lense distortion, that is, k_1 and k_2 are added to Case 3. (See Equation (4))

Table 4 Orientation Parameters

Case	Photograph	Unknown Parameters
Case 1	Single	$(X_0, Y_0, Z_0; \omega, \phi, \kappa)$
Case 2	Stereo	$(X_{0i}, Y_{0i}, Z_{0i}; \omega i, \phi i, \kappa i) i=1,2$
Case 3	Single	$(X_0, Y_0, Z_0; \omega, \phi, \kappa)(xp, yp, f)$
Case 4	Single	$(X_0, Y_0, Z_0; \omega, \phi, \kappa)(xp, yp, f; k_1, k_2)$

$$\text{Case 1:}\quad \sum_{j=1}^{n} (Vxj^2 + Vyj^2) \longrightarrow \min$$

$$
\begin{aligned}
x &= F(X_0, Y_0, Z_0; \omega, \phi, \kappa) \\
&= -f\frac{a_{11}(X-X_0)+a_{12}(Y-Y_0)+a_{13}(Z-Z_0)}{a_{31}(X-X_0)+a_{32}(Y-Y_0)+a_{33}(Z-Z_0)} \\
y &= G(X_0, Y_0, Z_0; \omega, \phi, \kappa) \\
&= -f\frac{a_{11}(X-X_0)+a_{12}(Y-Y_0)+a_{13}(Z-Z_0)}{a_{31}(X-X_0)+a_{32}(Y-Y_0)+a_{33}(Z-Z_0)} \\
Vxj &= Xj - Fj \mid X=Xj,\ Y=Yj,\ Z=Zj \\
Vyj &= Yj - Gj \mid X=Xj,\ Y=Yj,\ Z=Zj
\end{aligned}
\tag{1}
$$

where

$$
\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}
=
\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & -\sin\omega \\ 0 & \sin\omega & \cos\omega \end{bmatrix}
\begin{bmatrix} \cos\phi & 0 & \sin\phi \\ 0 & 1 & 0 \\ -\sin\phi & 0 & \cos\phi \end{bmatrix}
\begin{bmatrix} \cos\kappa & -\sin\kappa & 0 \\ \sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix}
$$

$$\text{Case 2:}\left\{ \sum_{i=1}^{n} \sum_{j=1}^{n} (Vxij^2 + Vyij^2) + \sum_{j=1}^{n} \Delta_j^2 \right\} \longrightarrow \min$$

$$
\Delta j = \begin{vmatrix} X_1j & Y_1j & Z_1j & 1 \\ X_{01} & Y_{01} & Z_{01} & 1 \\ X_2j & Y_2j & Z_2j & 1 \\ X_{02} & Y_{02} & Z_{02} & 1 \end{vmatrix}
\tag{2}
$$

where

$$
\begin{bmatrix} Xij \\ Yij \\ Zij \end{bmatrix}
= \begin{bmatrix} \omega i \end{bmatrix}\begin{bmatrix} \phi i \end{bmatrix}\begin{bmatrix} \kappa i \end{bmatrix}
\begin{bmatrix} xij \\ yij \\ -f \end{bmatrix}
+ \begin{bmatrix} X_0 i \\ Y_0 i \\ Z_0 i \end{bmatrix}
\qquad i = 1,2
$$

$$\text{Case 3:}\quad \sum_{j=1}^{n} (Vxj^2 + Vyj^2) \longrightarrow \min$$

$$
\begin{aligned}
x &= F(X_0, Y_0, Z_0; \omega, \phi, \kappa; xp, yp, f) \\
&= -f\frac{a_{11}(X-X_0)+a_{12}(Y-Y_0)+a_{13}(Z-Z_0)}{a_{31}(X-X_0)+a_{32}(Y-Y_0)+a_{33}(Z-Z_0)} + xp \\
y &= G(X_0, Y_0, Z_0; \omega, \phi, \kappa; xp, yp, f) \\
&= -f\frac{a_{11}(X-X_0)+a_{12}(Y-Y_0)+a_{13}(Z-Z_0)}{a_{31}(X-X_0)+a_{32}(Y-Y_0)+a_{33}(Z-Z_0)} + yp
\end{aligned}
\tag{3}
$$

Case 4: $\Sigma(Vxj^2 + Vyj^2) \longrightarrow \min$

$$
\begin{aligned}
x &= F(X_0,\ Y_0,\ Z_0;\ \omega,\ \phi,\ \kappa;\ xp,\ yp,\ f,\ k_1,\ k_2) \\
&= -f\,\frac{a_{11}(X - X_0) + a_{12}(Y - Y_0) + a_{13}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)} + xp - \overline{x}(k_1 r^2 + k_2 r^4) \\
y &= G(X_0,\ Y_0,\ Z_0;\ \omega,\ \phi,\ \kappa;\ xp,\ yp,\ f,\ k_1,\ k_2) \\
&= -f\,\frac{a_{11}(X - X_0) + a_{12}(Y - Y_0) + a_{13}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)} + yp - \overline{y}(k_1 r^2 + k_2 r^4)
\end{aligned}
\tag{4}
$$

where

$$
\begin{aligned}
\overline{x} &= x - xp \\
\overline{y} &= y - yp \\
r^2 &= \overline{x}^2 + \overline{y}^2
\end{aligned}
$$

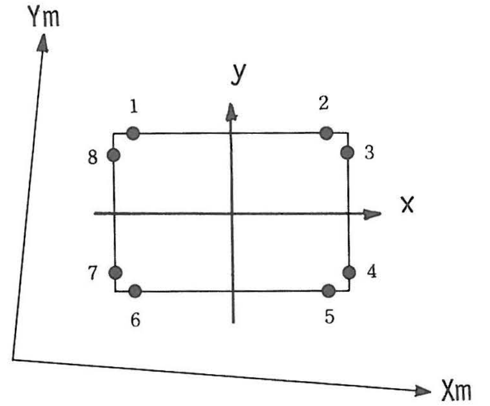


Fig. 3 Observation of Photographic Coordinates for Non-metric Camera

RESULTS OF TEST

a. Accuracy

Table 5 shows the root mean squares on negative film with respect to camera types and test cases.

Table 6 shows the mean relative accuracy, $\Delta Z/Z$ for base length of 12 meters.

Forme these results, the following conclusions were obtained.

1) When those interior orientation parameters such as position of principal point (xp, yp), local length f and lense distortion, k_1 and k_2 are determined together with six exterior orientation parameters, root mean squares on negative film ranges not more than 15μm, except for telescope lense of Hasselblad.

   This fact shows that non-metric camera except with telescope lense can be utilized with almost the same accuracy of not more than 15μm in RMS and 1/1000 in $\Delta Z/Z$, as those of metric camera. (See Case 4)

Table 5 Root Mean Squares on Negative Film with Respect to Camera Types and Test Cases (Unit: μm)

CASE / CAMERA	CASE 1	CASE 2	CASE 3	CASE 4
OLYMPUS	59.6	62.0	15.8	9.8
NIKON F2	14.5	15.1	23.0	10.0
NIKON F	20.3	20.9	30.9	12.1
HASSEL ST.	26.4	23.1	24.1	14.7
HASSEL WIDE	56.4	56.3	10.0	8.0
HASSEL TEL.	67.5	67.5	60.0	31.6

Table 6 Mean Relative Accuracy; ($\Delta Z/Z$) for Base Length of 12 Meters

CASE / CAMERA	CASE 1	CASE 2	CASE 3	CASE 4
OLYMPUS	1.918	1.922	1.238	0.714
NIKON F2	0.701	0.712	1.443	0.580
NIKON F	1.809	1.825	4.320	0.627
HASSEL ST.	2.060	2.048	1.495	0.499
HASSEL WIDE	1.212	1.220	0.937	0.765
HASSEL TEL.	0.961	0.982	2.139	4.986

(Unit : 10^{-3})

2) It can be said that NIKON F2 camera has powerful performance, even when interior orientation parameters are not considered. (See Case 1)

   This means that lense scheme, and frame of image format of NIKON F2 camera are geometrically registered.

3) From comparisons of results obtained from Case 1 and Case 2, difference of accuracy can not be recognized in both cases.

   This means that single photogrammetry is sufficient to determine those orientation parameters instead of stereo photogrammetry.

4) In the case of wide angle lense of Hasselblad, the accuracy was greatly improved from 56μm to 8μm interior orientation parameters were considered. This means that interior orientation parameters show great influences on accuracy.

b. Base length

Table 7 shows the comparisons of relative accuracy ($\Delta Z/Z$) with respect to base length for Case 4.

Relative accuracy $\Delta Z/Z$ can be approximately expressed in the following equation.

$$\frac{\Delta Z}{Z} \doteqdot \frac{H}{B} \frac{\Delta p}{f}$$

where

Δp : difference of parallax
f : focal length
H : distance to the object
B : base length

Supposed that Δp could be measured with the accuracy of 10μm on negative film, relative accuracy for the farthest object of which distance is H = 92 meters can be calculated as shown in Table 8.

Table 7 Comparisons of Relative Accuracy ($\Delta Z/Z$) with respect to Base Length

Camera \ Base	6 meters	12 meters
OLYMPUS	1.015	0.714
NIKON F2	1.275	0.580
NIKON F	2.281	0.627
HASSEL ST.	1.837	0.499

(Unit : 10^{-3})

Table 8 Theroretical Relative Accuracy ($\Delta Z/Z$) for H = 92m, B = 6m and 12m, and Δp = 10μm

Camera	f(mm)	Relative Accuracy ($\Delta Z/Z \times 10^{-3}$)	
		B = 6 m	B = 12 m
Olympus	50	3.07	1.53
Nikon F2	55	2.79	1.39
Nikon F	50	3.07	1.53
Hasselblad	80	1.92	0.96
	40	3.83	1.92
	250	0.61	0.31

(Unit : 10^{-3})

From those results of Table 7 and Table 8, the following conclusions are obtained.

1) Accuracy of test cases is much better than that of theoretical accuracy. This means that accuracy of observation can be estimated better than 10μm except in the case of telescope lense of Hasselbad.
2) In the case of base length B = 12m, relative accuracy is much improved as compared with the case of base length B = 6m.
3) The longer the focal length, the better the accuracy except telescope lense of Hasselbald.
4) In the case of telescope of Hasselblad, accuracy can not meat the normal criteria in photogrammetry.

APPLICABILITY OF NON-METRIC FILM TO PHOTOGRAMMETRIC PLOTTER

It is very important to produce a contour map by applying the non-metric film to conventional photogrammetric plotter, while three dimensional measurement to determine (X, Y, Z) by computer is possible as described before.

In the application of non-metric film to photogrammetric plotter, the following problems should be solved.

1) To enlarge the original nagative film two or three times with keeping flatness of film to obtain a diapositive which is applicable to photogrammetric plotter.
2) To rectify the convergent films to films with parallel axis to apply a conventional optical plotter.

   Above two problems can be solved by using a rectifier with galss plate to keep flatness of enlarged film.
3) To set up the true focal length depending on the times of enlargement.

   Analytical orientation will provide the true focal length.
4) To register an enlarged non-metric film without fiducial marks onto the glass plate of plotter.

This problem can be solved by overlaying a transparent film onto the glass plate, in which calculated photographic coordinates of control points are plotter by XY plotter as shown in Fig. 4.

Stereo pair of photographs taken by Nikon F2 were successfully set up in optical plotted of Wild A 10.

It is concluded that non-metric film can be applied to the conventional photogrammetric plotter, only when the above four problems should be carefully considered.

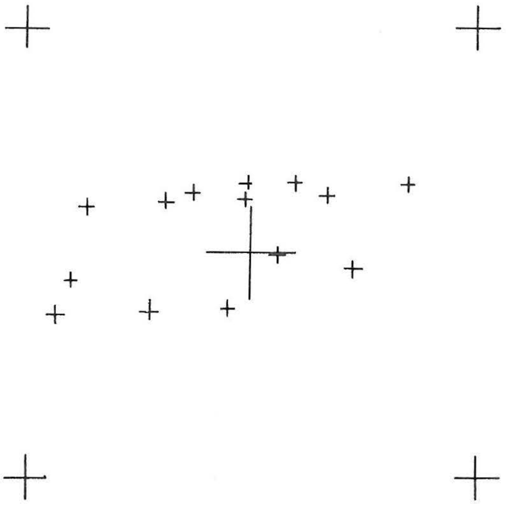


Fig. 4 Calculates Photographic Cooridnates of Control Points in Registered System

Fig. 5 Site of Mine Excavation

APPLICATION TO MINE EXCAVATION

A pair of stereo photographs were taken by non-metric camera of Hasselblad with wide angle lense, f=40mm in order to measure those three dimensional coordinates for cross sections of mine excavation, as shown in Fig. 5.

Seven control points were established, to determine both of exterior orientation parameters and interior orientation parameters. The nearest point from camera station was 90 meters and the farthest point was 270 meters.

Base length was 85 meters, which makes B/H ratio range 1:1.06 to 1:3.18.

Root mean squares of residuals on the negative film was 5μm, and mean relative accuracy ($\Delta Z/Z$) was 1.4×10^{-3} .

Maximum error of ΔZ was 0.49 meters while mean error of ΔZ was 0.26 meters.

This accuracy almost meets the criteria of 1 meter's contour accuracy, which was specified by the mine engineer.