ORIENTATION TESTS OF HIGH ALTITUDE AIRPHOTOS FOR ANALYZING THE LARGE FORMAT CAMERA(LFC) IN SPACE SHUTTLE

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Abstract:
This is a simulation test to estimate the measurment accuracy of three dimensional positions to be expected when LFC photographs can be used. The results of the author's experiments are as follows.

(1) accuracy of picture coordinates
  (a) 20 um (Combination of a diapositive and a stereo-comparator)
  (b) 80 um (Combination of enlarged photograph and a digitizer.

(2) accuracy of UTM coordinates of GCP
  (a) 20 m (using 1: 25,000 map)
  (b) 100 m (using 1:200,000 map)
  (c) 300 m (using 1:500,000 map)

(3) accuracy of absolute orientation of GCP in a LFC model
  (a) 30.9 m in horizontal, 51.5 m in height (for (a) of (1))
  (b) 150 m in horizontal, 250 m in height (for (b) of (1))

1. Introduction

The LFC(Large Format Camera) photos which are to take from the Space shuttle are capable to give us the three dimensional data. There are two kinds of method to aquire the height data from the stereoscopic pairs of LFC photos. The one method is conventional one and able to get the data as usual using the precise plotting machine. The other method is analytical one and firstly to measure the photo-coordinates by a digitizer and to orientate the photos by the data of geodetic control points measured on the maps.
The former method is precise but expensive to use the precise plotting machine which nobody can get and manage easily. The later one is not precise but everybody can easily use it by using simple and cheap digitizer. This paper describes on the test and result of those method.

2. Characteristics of Orientation of LFC Photographs

Space photographs as obtained by the Skylab S190A and S190B, or the Large Format Camera (LFC) on the space shuttle differ from conventional aerial ones in the following points:

(1) Geodetic control point (GCP)
In the orientation of the space photographs, no geodetic control points are prepared in advance, while they are set by small targets constructed by boards usually in the case of orientation of aerial photographs so far.

(2) Scale of photographs
Scale of aerial photograhs varies approximately from a scale of 1:5,000 to a scale of 1:100,000 when they are taken from altitudes of 750 to 15,000 meters using aerial camera with a focal length of 150 mm. Whereas, scales of space photographs are about 1:952,000 in the case of Skylab S190B, or 1:912,000 in a case of the space shuttle LFC photographs.

Table 1. Parameters of Five Types of Photograhs

No.	Platform/Camera	Altitude	Focal length	Image frame	Ground Resolution
		km	mm	mm mm	m
1	Skylab/S190A	435	152	57 x 57	40 - 46
2	Landsat/RBV	917	236	23 x 23	19
3	Skylab/S190B	435	457	114 x 114	17
4	Jet plane/RC10	12	152	230 x 230	1.5
5	Shuttle/LFC	278	305	230 x 460	20

To estimate the orientation accuracy of LFC photographs, there needs two kinds of investigations. One is from a side of orientation of GCPs in the ground coordinate system, for example, UTM coordinate system. Another is from a side of orientation of them in the picture coordinate system. As for the measurement of GCP in the ground coordinate system, the following methods can be chosen;
(1) Geodetic surveying in the field.
(2) Measuremet on the map
As for the measurement of GCPs in the picture coordinate system, the followng instrumets can be chosen;
(1) Comparator to measure the plane coordinates of GCP on the film.
(2) Digitizer to measure the plane coordinates of GCP on the paper print.

There is also a completely different method to know the three dimensional coordinates from space photographs. It is to orientate the photographs from the orbital parameters, i.e.,the position and attitude of the photographs in the photographing. Item (2) of GCP measurement in UTM coordinate system, and items (1) and (2) of GCP measurement in the picture coordinate system are examined in this paper.

3. Concept of Positioning Accuracy

There are two types of positioning accuracy in the orientation of three dimensional position. One is absolute accuracy which should be evaluated in the whole portions of a space photograph in a geodetic coordinate system. Another is relative accuracy which should be evaluated in the local portion of a space photograph in a local coordinate system. 'Local' appearing here means a relatively small portion in a space photograph.
In our experiences of orientation of aerial photographs so far, the above absolute accuracy is in a level of about 1:1,000 to 1:4,000 against the photographing altitude.
On basis of the law of propagation error in additive operation, the expected error of parallel parallax becomes $\sqrt{2}$ dx in a pair of photographs, in an assumption that dx is the mean error associated with the point orientation on a picture plane.

Fig. 1 shows a concept of errors of three dimensional position of the GCP target, when the error are caused mainly from the positioning errors of it in the picture coordinates.
Let horizontal and height errors of the point P be dX and dH respectively,

$$dX = H (dx1 + dx2)/f \qquad (1)$$

$$dH = H^2 (dx1 + dx2)/(Bf) \qquad (2)$$

where,

H : flight height above the point P
f : focal length
B : base line length
x1, x2 : positioning errors occured in the two picture plane

Erquations (1) and (2) can be expressed by the following equations respectively in the assumption of the low of propagation error for the mean error 'dx' on each picture coordinates system.

$$dX = \sqrt{2}\ H/f\ dx \qquad (3)$$

$$dH = \sqrt{2}\ H^2/(Bf)\ dx = H/B\ dX \qquad (4)$$

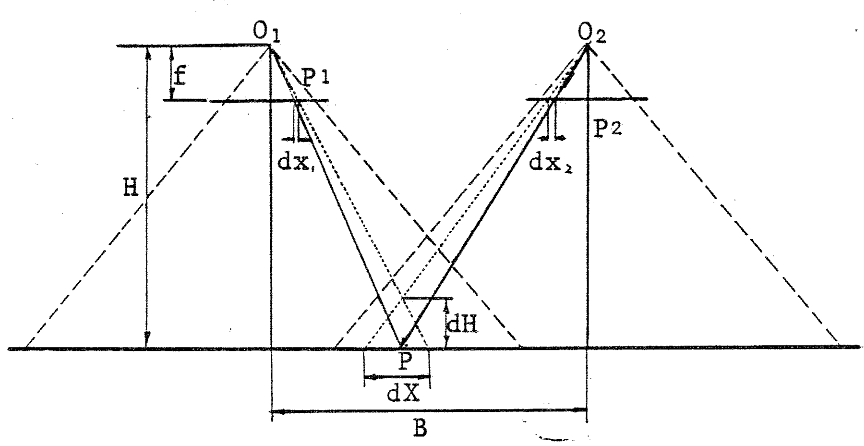

Fig.1 Three dimensional errors at an object point caused by the errors in the picture plane

4. Measurement of GCP Coordinates by Digitizer

First experiment deals with the accuracy of three dimensional positioning of GCP using a digitizer. High altitude stereo-photographs of Tokyo district covering an area of about 10 km x 18 km as shown in Fig.2 are chosen for the test data. Fig.3 shows the orientation process of stereo-photographs.
First, the high altitude photographs obtained from an altitude of about 12,000 meters by a RC-10 camera with a focal length of 152.62 mm are enlarged to a scale of approximately 1:25,000. This is attained by an enlargement of x 3.3, since the original scale of photographs is approximately 1;80,000. A scale of 1:25,000 is same that of a 1:25,000 topographical map published from the Geographical Survey Institute of Japan.

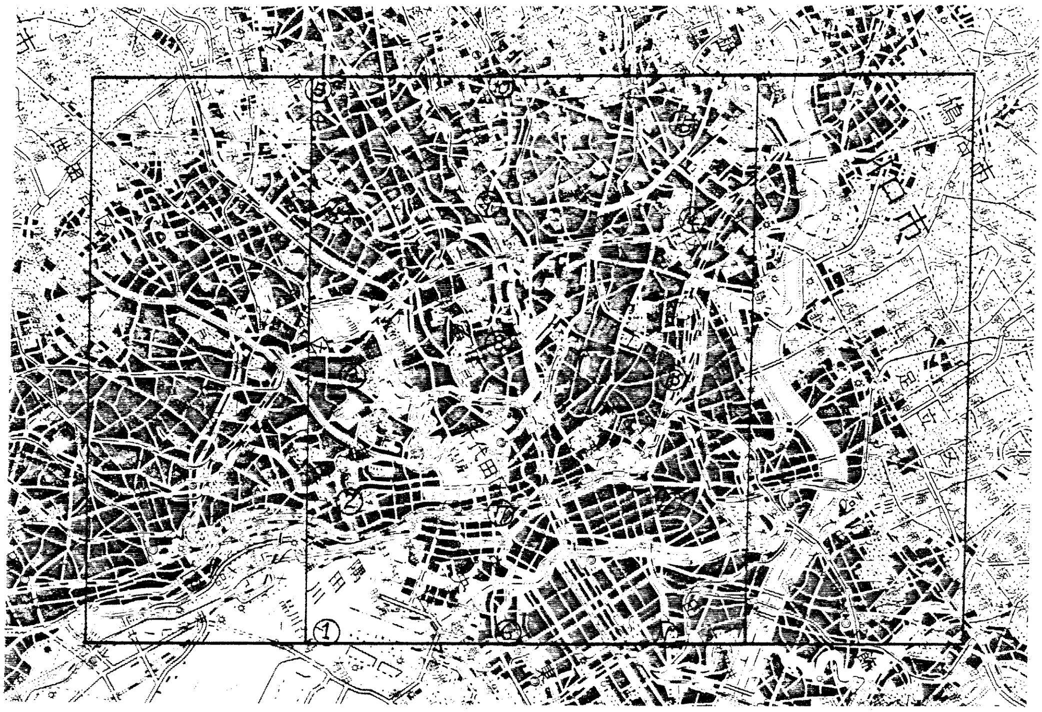

Fig.2 Coverage of the test aerial photos and 15 GCP locations

(1) Enlargement of the Stereo-photos (to an apx.1:25,000 paper print)

(2) Measurement of picture coordinates (at 4 fiducial marks and 15 GCPs as shown in Fig.4)

(3) Projective transformation of GCPs (controled at 4 fiducial marks)

(4) Reading of geodetic Coordinates of GCPs on 1:25,000 maps

(5) Relative and absolute orientations of stereo-photos at 15 GCPs

Fig.3 Orientation procedure of stereo-photographs

Table 2 Geodetic Coordinates of GCP (obtained from 1:25,000 maps)

GCP	latitude	longitude	height
1	35° 37' 58"	139° 47' 19"	5 m
2	35° 39' 3"	139° 44' 54"	6 m
3	35° 40' 9"	139° 42' 57"	30 m
4	35° 40' 59"	139° 40' 21"	35 m
5	35° 41' 31"	139° 38' 9"	40 m
6	35° 40' 3"	139° 48' 21"	0 m
7	35° 40' 56"	139° 46' 26"	24 m
8	35° 42' 6"	139° 44' 2"	25 m
9	35° 43' 9"	139° 41' 45"	36 m
10	35° 44' 1"	139° 39' 49"	39 m
11	35° 42' 7"	139° 49' 45"	0 m
12	35° 43' 3"	139° 47' 40"	2 m
13	35° 44' 15"	139° 45' 37"	24 m
14	35° 45' 16"	139° 43' 32"	20 m
15	35° 45' 59"	139° 41' 55"	25 m

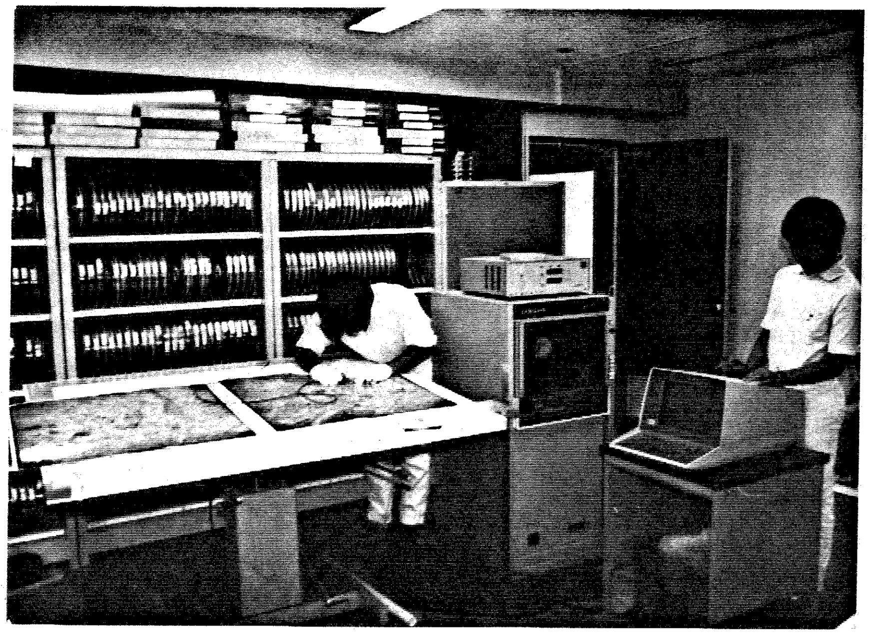

Fig.4 Measurement of picture coordinates using a digitizer

Next, picture coordinates of 4 fiducial marks and 15 geodetic control points are measured on the enlarged photographs as shown in Table 1 by a digitizer(Fig.4) with a measurement unit of 10 µm (<micro-meters). Positions to be observed are pricked in advance by comparing each pair of targets on the stereo-photographs and also the location of the corresponding map. Fig.5 and Fig.6 are the figures of these 15 GCPs on photographs and on maps respectively and the characteristics of these are as follows.

Interpretation about GCP

GCP 1: Corner of a pier, positive to be distinguished both on the photograph and the map. Errors of the elevation may occur, becususe of the difference of elevation between sea level and the surface of the pier.

GCP2: Corner of an intersection, positive to be distinguished both on the photograph and on the map. The elevation data is also positive to be obtained on the map.

GCP 3: Corner of an intersection, not easy to be distinguished on the photograph because of shadows of the neighboring buildings. Elevation data is easy to be mistaken because that the GCP consists of a multi-level crossing.

GCP 4: Corner of an intersection, positive to be distinguished on the map, but negative on the photograph because of building shadows.

GCP 5: Corner of an entrance of a canal, clear on the photograph and the map, but the width of this canal on the photograph differs from that on the map.

GCP 6: Corner of an entrance of a canal, same as of GCP 5.

GCP 7: Crossing of a highway and the lower ordinary road, positive on both the photograph and the map, but the distortion of the images on the stereo-photographs may produce a elevation error.

GCP 8: Corner of an intersection, width of the road on the photograph differs from that on the map.

Fig.5 Images of 15 GCPs on the photographs

Fig.6 Locations of 15 GCPs on 1;25,000 map

GCP 9: Corner of an intersection, not easy to be distinguished on the photograph becase the building shadows, and also because of width difference of the road in the photograph and the map.
GCP 10: Corner of an intersection, same as of GCP 8.
GCP 11: Corner of an intersection, same as of GCP 8.
GCP 12: Parting of two ways, positive to be distinguished both on the photographs and the map. The elevation data is also positive to be read on the map.
GCP 13: Parting of railways, positive on the photograph, but not easy on the map.
GCP 14: Crossing of a road and a railway, the errors may occur because the width difference of the road between on the photograp and the map.
GCP 15: Corner of an intersection, positive to be distinguished both on the photograph and the map. But, because of the roughness of topography may produce an error in the elevation data.

Converting the latitude and longitude of GCPs in Table 2 to the corresponding values by a UTM coordinate system, relative and absolute orientation were carried out. Table 3 shows the result. Vertical parallaxes in the relative orientation become about 100 μm. Scince the measuring unit of the digitizer is 10 um, a value of 20 to 30 μm as the probable error had been estimated. This result is, however, not reach the above predicted accuracy.
Also, the results of absolute orientation are in a level of accuracies of 6.9 meters in horizontal direction, and 13.9 meters in height direction both in standard deviation.
Becase of 12,000 meters of the photographing altitude, the accuracy of height direction becomes 1/860 in standad deviation.
In this connection, the authors had predicted an accuracy of 1/1,000 in this experiment in advance.

Table 3 Orientation Accuracy of High Altitude Photographs (in the case using a digitizer)

	GCP Coordinates (UTM)			Residual Errors			
	X m	Y m	H m	V.P. μ	d X m	d Y m	d H m
1	3,943,529.4	389,569.8	5.0	-72.5	-10.0	0.0	-20.5
2	3,945,550.4	386,716.9	6.0	118.2	-1.2	-2.4	1.2
3	3,947,608.0	383,779.2	30.0	7.6	9.9	-8.4	10.6
4	3,949,202.0	379,881.5	35.0	-59.8	0.0	-0.1	-4.1
5	3,950,236.7	376,580.0	40.0	12.6	7.8	-4.8	-20.5
6	3,947,322.7	391,919.0	0.0	-7.6	1.2	5.3	1.0
7	3,949,006.7	389,058.2	24.0	-19.4	-3.4	-4.5	15.4
8	3,951,204.3	385,467.0	25.0	-5.8	2.2	0.4	5.0
9	3,953,184.7	382,057.4	36.0	77.2	12.2	-12.7	-2.0
10	3,954,822.6	379,165.4	39.0	-45.3	1.9	-14.3	-5.3
11	3,951,117.7	394,094.3	0.0	104.0	0.1	-3.9	-4.3
12	3,952,907.7	390,979.1	2.0	-115.7	-2.3	0.7	1.2
13	3,955,153.7	387,904.1	24.0	-105.3	-17.1	5.4	19.2
14	3,957,057.9	384,804.5	20.0	156.6	4.1	-15.5	-0.1
15	3,958,410.1	382,374.4	25.0	-45.5	-2.8	1.6	-34.2
Standard Deviations (n-1)				81.7	7.3	7.5	14.2

5. Occurrence of Error in Above Orientation Process

Errors of GCP coordinates occured in the orientation of stereo-photographs can be categorized to various types. The types are summarized to the following three items.

(1) When the different targets are identified as a same one.

When similar two targets exist in very near places in chosing GCP on stereo-photographs, the two different targets may happen to be identified as a same target. This kind of error happened in GCP 15.

(2) When the elevation of target is mistaken.

When a architectural construction is seen on the stereo-photographs, a corner of the top surface of it used to be chosen. But, the values of the elevation indicated on a map is that of the ground level. If, this value might be assigned

Table 4 UTM Coordinates of GCP Measured on Various Maps and Deviations

	from 1:25,000 map		from 1:200,000 map		from 1:500,000 map	
	X m	Y m	X m	Y m	X m	Y m
1	3,943,520	389,570	3,943,573	389,521	3,943,340	389,459
2	3,945,550	386,717	3,945,517	386,690	3,945,402	386,620
3	3,947,608	383,779	3,947,710	383,851	3,947,739	383,605
4	3,949,202	379,882	3,949,236	380,193	3,949,785	379,501
5	3,950,237	376,580	3,950,240	376,580	3,950,561	376,743
6	3,947,323	391,919	3,947,234	391,993	3,947,234	391,993
7	3,949,007	389,058	3,948,934	389,086	3,948,688	388,931
8	3,951,204	385,467	3,951,201	385,457	3,950,732	385,590
9	3,953,185	382,057	3,953,276	382,109	3,952,848	381,969
10	3,954,823	379,165	3,954,953	379,460	3,954,819	378,626
11	3,951,118	394,094	3,951,179	394,129	3,951,276	394,129
12	3,952,908	390,979	3,952,866	390,987	3,952,930	391,131
13	3,955,154	387,904	3,955,214	387,760	3,954,951	387,307
14	3,957,058	384,805	3,957,095	384,833	3,956,767	384,754
15	3,958,410	382,374	3,958,456	382,347	3,958,335	381,509
			dX m	dY m	dX m	dY m
1			-53	48	180	110
2			33	26	148	97
3			-102	-71	-131	174
4			-34	-311	-583	380
5			-3	0	-324	836
6			89	-74	89	-74
7			73	-27	319	127
8			3	10	474	-122
9			-91	-51	337	88
10			-130	-294	4	539
11			-61	-34	-158	-34
12			42	-7	-22	-151
13			-60	144	203	596
14			-37	-28	291	50
15			-46	27	75	865
Mean			-25	-43	60	232
S.D.			62	145	267	322

accidentaly, a mistake will be caused. This kind of error happened in GCP 7, since triple overlapped constructions, a road on ground level, a high story rail road, and a more high story highway, exist in this densely build up area of central Tokyo.
(3) When the origin of the map itself is mistaken.
When the origin of the map itself is mistaken, a large error will occur. This kind of error happened in the map including GCP 6.

6. Accuracies of UTM coordinates of GCP Using Various Scales of Maps

When various scales of maps are used to know the UTM coordinates of GCP, how large errors will happen? Investigation for this question is carried out in the case of 1:200,000 geographical map and of 1:500,000 map both published from GSI.
Table 4 shows the UTM coordinates of 15 GCPs measured on three kinds of maps. Each coordinates were measured by latitude and longitude and then converted to the UTM coordinates.
Deviations of the GCP coordinates by a 1:200,000 map from those by 1:25,000 maps are shown in the lower portion of Table 4.
Also deviations of the GCP coordinates by a 500,000 map from those by 25,000 maps are shown in the same portion. Means and standard deviations in the both cases can be said to be approximately a magnitude of 0.5 mm by the distance on any map.

Table 5 Stecometer Coordinates of GCP and the Measurement Fluctuations

	First trial				Second trial				Fluctuation (μ)			
F.M.	Xμ	Yμ	PXμ	PYμ	Xμ	Yμ	PXμ	PYμ	dX	dY	dPX	dPY
1	500000	500000	500000	500000	499999	500012	500014	499999	-1	12	14	-1
2	711909	499852	499988	500378	711910	499858	499984	500389	1	8	-4	11
3	711383	287938	499609	500364	711389	287932	499595	500367	6	-6	-14	3
4	499442	288069	499628	499974	499441	288060	499629	499960	-1	-9	1	-14
GCP NO.								Mean S.D.	1.3 2.9	1.3 8.9	-0.8 10.0	-0.3 9.0
1	586999	302728	579134	500821	586965	302739	579105	500809	-34	11	-29	-12
2	591067	346628	579902	500588	591068	346668	579898	500629	1	40	-4	41
3	594905	391619	580785	500593	594892	391641	580798	500625	-13	22	13	32
4	587653	443612	581622	500620	587673	443616	581652	500670	20	4	30	50
5	578207	485342	582383	500875	578228	485376	582352	500893	21	34	30	18
6	643756	302276	579488	502139	643803	302334	579513	502167	57	58	25	28
7	643521	344037	580101	501774	643537	344052	580133	501773	16	15	32	-1
8	644559	396914	580887	501566	644527	396902	580889	501582	-32	-12	2	16
9	644402	446307	581645	501660	644380	446324	581651	501646	-22	17	6	-14
10	643565	487738	582162	501898	643572	487716	582161	501908	7	-22	-1	10
11	699123	303654	580153	503416	699115	303660	580140	503452	-8	6	-13	36
12	698392	348935	580594	502865	698427	348991	580619	502833	35	56	25	-32
13	702786	395644	581182	502703	702787	395669	581183	502737	1	25	1	34
14	703647	442277	581717	502678	703651	442255	581718	502682	4	-22	1	4
15	702483	476601	581973	502810	702496	476614	581975	502805	13	13	2	-5
								Mean S.D.	4.4 23.7	16.3 23.6	8.0 17.0	13.7 22.7

7. Accuracy of Picture Coordinates of GCP Using a Stecometer

When picture coordinates of GCP are measured by a stereo-comparator, how large errors happen? Four fiducial marks and 15 GCPs seen on the stereo-photographs were measured using an old Stecometer of the University.
Two trials of the measurement of GCPs were carried out. Differences of the second values from the first ones of each same GCP are listed as shown in Table 5. Standard deviations are almost 24 µm on the averrage. Performing a relative and absolute orientations to those obtained picture coordinates, the residuals at 15 GCPs become to the values in Table 6. Compared with the previous result in Table 3 in the case using a digitizer, this result has a small improvement.

8. Concluding Remarks

Obtained satndard deviations of the measured values of picturecoordinates of GCP by (1) a comparator, and (2) a digitizer, are 23.7 µm (from Table 5) and 81.7 µm (from the V.P. in Table 3) respectively in the authors' experiments.
Horizontal and height errors in UTM coordinate system lead to dX =2.6 meters and dH = 4.4 meters for the above values of 23.7 um and dX = 9.1 meters and dH = 15.2 meters for the above value of 81.7 um, in the case of applying Equations (3) and (4). The corresponding residual errors are dX = 22.3 meters, dY = 27.7 meters, and dH = 6.0 meters as shown in Table 6. These values show as the better results under such conditions as the relative orientation of stereo- photographs is performed in high accuracy but the GCP coordinates are rather uncirtain in the maps.

Table 6 Orientation Accuracy of High Altitude Photographs (in the case using a stereo-comparator)

	GCP Coordinates (UTM) X m	Y m	H m	Residual Errors V.P. µ	d X m	d Y m	d H m
1	3,943,529.4	389,569.8	5.0	-9.0	29.6	-6.4	-11.5
2	3,945,550.4	386,716.9	6.0	-2.9	6.8	4.6	-2.5
3	3,947,608.0	383,779.2	30.0	6.5	-2.2	-2.5	0.8
4	3,949,202.0	379,881.5	35.0	-4.4	-13.8	-24.7	-2.9
5	3,950,236.7	376,580.0	40.0	14.0	-20.1	-56.8	-7.6
6	3,947,322.7	391,919.0	0.0	3.6	39.4	0.6	-4.7
7	3,949,006.7	389,058.2	24.0	17.7	1.3	6.8	-16.5
8	3,951,204.3	385,467.0	25.0	5.0	-5.8	10.7	-4.6
9	3,953,184.7	382,057.4	36.0	-5.8	0.3	-4.4	3.6
10	3,954,822.6	379,165.4	39.0	-28.1	0.5	-38.7	-2.5
11	3,951,117.7	394,094.3	0.0	15.6	2.0	-15.8	-1.9
12	3,952,907.7	390,979.1	2.0	-45.3	-5.6	2.3	-0.7
13	3,955,153.7	387,904.1	24.0	16.0	-61.6	69.9	-9.8
14	3,957,057.9	384,804.5	20.0	-2.4	0.9	-1.4	6.9
15	3,958,410.1	382,374.4	25.0	19.4	-0.1	1.3	-8.0
Standard Deviations (n-1)				17.8	22.3	27.7	6.0

Substituting typical orientation parameters of LFC to Equations (3) and (4), i.e., H = 278 km, B/H = 0.6, dx = 24 µm (from the auther's experiences), and f = 305 mm, the following mean square errors can be obtained; dX = 30.9 m and dH = 51.5 m.
When using a digitizer, the residual errors increse approximately 5 times of the value by a comparator. In this case, the horizontal and height errors in three dimensions are almost 150 meters in horizontal direction and 250 meters in height respectively.
These values are the results of the cases for all GCP in which the absolute orientation procedure have been done for the entire area covering the all geodetic control points(GCPs).
The values shown in Reference (1) indicate high accuracy as 14 meters in horizen and 14 meters in height. Also Dr. Doyle's report shows very high performace of LFC-Pan camera system. Namely, relative and absolute mapping errors are 10 and 17 meters in plane position, and 10 and 14 meters in elevation respectively.
Simulated results in the authors' experiments, however, does not show such a high performance. It is considered that when enlarged stereo-photographs with high resolution are obtained, such high performance may be attained in very small local area using a digitizer.
The results obtained by the authors through this experiments are summarized as follows;
(1) Measurement accuracy of GCP in picture coordinate system is almost 20 um as of mean square errors of the 15 GCPs in a case of using a diapositive film and a stereo-comparater, and also of 80 um in a combination of enlarged photographs and a digitizer.
(2) Measurement accuracies of GCP in UTM coordinate system are standard deviations of almost 100 meters in a case of 1:200,000 geographical map, and of almost 300 meters in a case of a 1:500,000 map.
(3) Elevation of GCP is rather difficult to be decided by reading on maps of small scales of 1:200,000 or 1:500,000.

From the above mentioned items, elevaion data of GCP are important in the orientaion compared to the plane position coordinates even in the case of the simple orientation procedures using a digitizer. To solve this problem, two approachs may be considered; (1) to obtain accurate elevation data of GCP by the field surveying, (2) to obtain accurate camera position and attitude decided from orbital parameters.

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