AN ADJUSTMENT OF PHOTOGRAMMETRY COMBINED WITH THE DEOGETIC DATA AND GPS

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ABSTRACT

The objective of the study is to develop a method of simultaneous adjustment (MSA) to determine the exterior orientation parameters of a single photograph together with X,Y,Z coordinates of unknown points using the additional observations obtained from the geodetic survey. The additionl obsevations such as measurement of distances, horizontal angles and vertical angles enable three dimensional positioning of unknown points even on a single photograph. In order to evaluate the MSA, a simulation study was done.

The Global Positioning System (GPS) is a new type of the additional observations, which will also improve the accuracy of exterior orientation, especially for a photograph taken by a narrow angle camera. New types of satellite images such as LANDSAT, SPOT, MOS etc, has a narrow angle field of view though they are not based on central projection. In such case, control points are not sufficient to determine exterior orientation parameters with high accuracy, Where GPS will remarkably improve the accuracy of the exterior orientations.

In this study, another simulation has been done with respect to the relation between the field of view, accuracy of exterior orientation parameters and the effect of GPS. Finally, the authors has summarized the MSA into several typical categories with respect to which information are utilized from the geodetic surveys and GPS.

1. Intoduction

The photogrammetry with a single photograph had not become a practical method to obtain X,Y and Z coordinates without under a special or restricted condition. Therfore, the photogrammetric adjustment for multiple photographs in strip or block has been developed. However much work is needed for geodetic control in the block adjustment. Many attempts to decrease the ground control have been investigated[1)-3)] .

In accordance with the development of electro-optical distancemeter, the triangulation in the geodetic survey on the ground is being replaced by the trilateration. A combined adjustment taking into consideration of distance measurement has been examined[4)] . The GPS has become a new navigation system to observe the camera position in flight as well as any 3D position on the ground or any distance between receivers. It was made clear that the data from GPS are very useful for reducing the ground control[5)-8)] .

Recently a photogrammetric orientation for satellite images such as SPOT stereo images should be developed to determine exterior orientation parameters and 3D coordinates of terrain points. Such satellite images used to be taken by CCD camera with very narrow angle, for example, 4.2 degree in SPOT case. Additional observations such as distances, heights, angles and/or data from GPS would be very useful for a new type of space-triangulation.

2. The MSA with measurements by geodetic survey

2-1. The MSA equation

In this study, the following corrections can be taken into account in the least square method.

1) photographic coordinates (Δx_i, Δy_i)
2) distance (Δl_{ij})
3) ground coordinates ($\Delta X_i, \Delta Y_i, \Delta Z_i$)
4) height or vertical angle $Z_r = l_r sin\alpha_r + Z_i$
   where, Z_i ;height of control point, l_r ;slope distance, α_r ;vertical angle
5) linearity

In case of measurement of horizontal, a linearity equation for a straight line of A and C in Fig.2-1 on which point B should be located.

$$U=(X_B-X_A)(Y_C-Y_A)-(X_C-X_A)(Y_B-Y_A) \quad : \text{clockwise}$$

$$W=(X_B-X_A)(Y_E-Y_A)-(X_E-X_A)(Y_B-Y_A) \quad : \text{anti-clockwise}$$

6) horizontal angle $\Delta\theta_i$ (see Fig.2-2)
   $\Delta\theta_D$: closure error of clockwise
   $\Delta\theta_R$: closure error of anti-clockwise
7) camera station $\Delta X_0, \Delta Y_0, \Delta Z_0$
   observated coordinates are given by GPS

In a practical application, all above corrections will not be used simultaneouslly. According to the type of geodetic survey, the following cases are commonly used.

Case 1 : Combined with distance measurement
The least square equation is as follows;

$$G_1=\{[p_1(\Delta x_i^2+\Delta y_i^2)]+[p_2(\Delta l_{ij}^2)]+[p_3(\Delta X_i^2+\Delta Y_i^2+\Delta Z_i^2)]\} \quad \text{.........(2-1)}$$

where, [ ] ; summation p_i ; weight

Case 2 : Combined with measurement of distances and vertical angles

$$G_2=\{[p_1(\Delta x_i^2+\Delta y_i^2)]+[p_2(\Delta l_{ij}^2)]+[p_3(\Delta X_i^2+\Delta Y_i^2+\Delta Z_i^2)]+[p_4(\Delta Z_r^2)]\} \quad \text{.......(2-2)}$$

Case 3 : Combined with measurement of horizontal angles

$$G_3=\{[p_1(\Delta x_i^2+\Delta y_i^2)]+[p_3(\Delta X_i^2+\Delta Y_i^2+\Delta Z_i^2)]+p_5(\Delta U_i^2+\Delta W_i^2) +p_6(\Delta\theta_D^2+\Delta\theta_R^2)+[p_6(\Delta\theta_i^2)]\} \quad \text{...........(2-3)}$$

Case 4 : Combined with measurement by GPS

$$G_4=\{[p_1(\Delta x_i^2+\Delta y_i^2)]+[p_2(\Delta l_{ij}^2)]+[p_3(\Delta X_i^2+\Delta Y_i^2+\Delta Z_i^2)] + p_7(\Delta X_0^2+\Delta Y_0^2+\Delta Z_0^2)\} \quad \ldots\ldots\ldots\ldots\ldots(2\text{-}4)$$

2-2. Initial apporoximate values

As the above combined adjustment is expected a very complicate non-linear function, the solution strongly depends on the initial apporoximate values. This was clarified in the simulation test as mentioned later.

Two methods to give or calculate the initial apporoximate values of exterior orientation parameters and unknown/unadjusted control points have been utilized.

Method 1 : Plane Apporoximate Method of Simultaneous Adjustment (PAMSA)

The initial apporoximate values are computed under the assumption that object plane are flat, where the two dimensional projective transformation is available.

Method 2 : Three-points Apporoximate Method of Simultaneous Adjustment (TAMSA)

Three control points are given in a single photograph to determine the apporoximate orientation parameters.

2-3. The weight

Appropriate weights should be given to the MSA equation as shown above. In this study the following three cases were evaluated and compared.

Case 1) Weight derived from probability theory
Case 2) Weight based on the accuracy of measurement machine
Case 3) Equal weight

The result of simulation test showed that influence by different combination of weights was very little with respect to the above three cases. Therfore, in the following discussion, the following weights are commonly used as shown in Table 1.

3. Simulationta Tests for Aerial Photogrammetry

Simulation tests for a simple model as shown in Fig.3-1 were carried out to evaluate the MSA. The model was based on an aerial photograph, which was actually taken at 1/3000 scale. The true value of 5 points were artificially given, as shown in Table 3-1. The observed values in Table 3-1, 3-3 and 3-4 were given by adding a random error. Table 3-2 shows the true exterior orientation parameters computed with use of true control points.

Case 1 :Combined with distance measurement ;

Three points of A, B and C were treated as control points, but has errors. Table 3-5 shows the result for the case 1. The adjusted coordinates had mean errors of 0.013m in ΔX, 0.010m in ΔY, 0.058m in ΔZ. The mean error in distance was 0.006m.

Case 2 :Combined with measurement of distances and vertical angles; Two points of A and B were treated as control points. Table 3-6 shows the result for the case 2. Planimetric accuracy was almost same with case 1, while the accuracy for height and distance was tremendously improved. When the relative coordinate system is allowed, that is, point A has (0,0,0) for example, the accuracy will be a little improved as shown in Table 3-7.

Case 3:Combined with measurement of horizontal angles; Three points of A, B and C were treated as control points. Table 3-8 shows the result of the case 3. The result was almost similar with other cases except the height accuracy which was the worst in all cases. If the height apporoximates are given by the measurement of vertical angles, the height accuracy was improved almost ten times as shown in Table 3-9.

Case 4 :Combined with measurement by GPS; The following four types were taken into account as shown in Fig.3-2.

Type I : Camera station (X_0,Y_0,Z_0) is only given by GPS, while distances between points on the ground are observed by distancemeter.

Type II : Camera station (X_0,Y_0,Z_0) and ground coordinates (X_i,Y_i,Z_i) are given by GPS.

Type III : Distances (l_{ij}) and ground coordinates (X_i,Y_i,Z_i) are given

Type IV : Camera station (X_0,Y_0,Z_0), distances (l_{ij}) and ground coordinates (X_i,Y_i,Z_i) are given.

In the simulation tests, the following four mean errors were assumed for positioning a camera station.

1) Very high accuracy : ± 1m
2) High accuracy : ± 5m
3) Normal accuracy : ± 10m
4) Low accuracy : ± 50m

Random errors were given to all ground points in the following five mode.

1) Mode 1 : ± 5cm
2) Mode 2 : ± 1m
3) Mode 3 : ± 5m
4) Mode 4 : ± 10m
5) Mode 5 : ± 50m

The simulation tests were evaluated which type of GPS utilization can reach a certain of accuracy. The criteria in this tests were set up as follows;

Criteria 1 : Very low accuracy within ± 10m on the ground.
Criteria 2 : Low accuracy within ± 5m on the ground.
Criteria 3 : High accuray within ± 1m on the ground.

Table 3-10 shows the evaluation of the four types of GPS utilization with respect to the four mean errors of camera station and the five modes of random errors. A blank means that the specified crieteria can not be achived.

4. Simulation tests for space photogrammetry

As mentioned before, an exterior orientation for space image taken by narrow angle camera should be investigated in the space age. A simulation test model was set up as shown in Fig.4-1. Three different angles of wide (86 degree), normal (50 degree) and narrow (20 degree) were taken into account. In each case, five control points were given under the assumption that the object plane is flat. The mean error of control points was set up as follows;

1) Very heigh accuracy : ± 1m
2) High accuracy : ± 5m
3) Low accuracy : ± 10m

The positioning errors of camera station were varied in the simulation as follows;

a) No use of GPS
b) Use of GPS
   1) ± 2m
   2) ± 5m
   3) ± 10m
   4) ± 50m

As the tendency of accuracy for orientation parameters with respect to the mean error of control points is similar each other, only the comparison between no use of GPS and use of GPS in ± 10m is shown in Fig.4-2. Fig.4-2 (a) shows the accuracy of rotation angles (ω, ϕ, κ), and Fig.4-2 (b) shows the one of shifting parameters (X_0,Y_0,Z_0).

The narrower the field of view is the worse the accuracy was in the case of non use of GPS. However, the accuracy was very stable in the case of use of GPS.

5. Categorization of the MSA

The MSA can be classified¥in the four categories as shown in Fig.5-1.

Caregory Ⅰ : Radial type
Four cases can be considered as shown in Table 5-1 with respect to type of control points, number of control points, number of unknowns, number of observations, type of geodetic survey. The figures are corresponding to the simple model shown in Fig.3-1.

Category Ⅱ : Chain type
Between points, distances or heights are measured in a chain type. Three cases can be listed in Table 5-1.

Category Ⅲ : GPS type
Three cases are considered as shown in Table 5-1.

Category IV : Ruler type

Two rulers with known distances are placed as follows.

1) Two rulers are placed on the same plane almost horizontally, where the height measurement is not necessary to get the initial apporoximate values.
2) Two rulers are placed almost horizontally but not on the same plane, or placed not horizontally each other where the height measurement is necessary to get the initial apporoximate values.

Conclusion

1) A combined adjustment (MSA) for a single photograph using measurement of distances, heights, horizontal angles, vertical angles, camera station by geodetic survey or GPS has been developed by the authors.
2) MSA was very effective in reducing the number of control points, determining three dimensional coordinates of unknown points, detecting gross errors etc.
3) Utilization of GPS was very useful to stabilize the accuracy of orientation in the simulation tests even for a narrow angle camera.
4) MSA will be utilized and categorized according to the circumstances of ground control or GPS.

References

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Table 1 The weight in this paper

case		unit	accuracy	weight
I II III	photogrammetric coordinates	μm	1 μm	1000
	distance	mm	1 mm	1
	angle	sec	5 ″	40000
	ground coordinates	mm	3-30 mm	1
	linearity	-	-	1
IV	camera station by GPS		1 m	0.0025
			5 m	0.0001
			10 m	0.00025
			50 m	0.000001

Table 3-1 Coordinate of Control Points

control point	ground coordinate True Value X(m)	Y(m)	Z(m)	Measurement Value X(m)	Y(m)	Z(m)	photo-coordinate x(mm)	y(mm)
A	-13615.222	-30414.893	85.292	-13615.230	-30414.890	85.270	43.904	-38.124
B	-13392.607	-30265.466	36.820	-13392.609	-30265.476	36.826	87.126	44.361
C	-13586.767	-30619.308	36.251	-13586.772	-30619.301	36.238	79.763	-93.777
D	-13779.863	-30512.109	37.345	-13779.877	-30512.115	37.315	4.279	-89.571
E	-13642.382	-30113.646	63.152	-13642.360	-30113.660	63.180	-13.429	56.145

Table 3-2 True Values of Exterior Orientation Parameters

X_o = -13673.473 m	ω = 0° 14′ 23.7″
Y_o = -30270.038	ϕ = -0 15 22.1
Z_o = 660.029	κ = 25 50 4.0

Table 3-3 Observed Distances

line	Distance(m)
AB	272.467
AC	212.133
AD	197.108
AE	303.280
CB	403.622
CD	220.858
EB	293.472
ED	422.290

Table 3-4 Observed Angle

Telescope	No.	Horizontal	Vertical
Direct	1	115° 56′ 35″	-10° 14′ 55″
	2	67 21 40	-13 22 5
	3	115 24 35	-14 4 50
	4	61 16 50	-4 11 10
Reverse	4	61 16 55	
	3	115 24 25	
	2	67 21 50	
	1	115 56 45	

Table 3-5 Case 1:Combined with distance measurement

	ΔX(m)	ΔY(m)	ΔZ(m)	Δl(m)
Max. Error	0.031	0.036	0.156	
Mean Error	0.013	0.010	0.058	0.006

Table 3-6 Case 2:Combined with measurement of distances and vertical angles

	ΔX(m)	ΔY(m)	ΔZ(m)	Δl(m)
Max. Error	0.028	0.046	0.023	
Mean Error	0.017	0.012	0.018	0.001

Table 3-7 Case 2:Combined with measurement of distances and vertical angles in relative coordinate system

	ΔX(m)	ΔY(m)	ΔZ(m)	Δl(m)
Max. Error	0.018	0.043	0.029	
Mean Error	0.011	0.011	0.010	0.001

Table 3-8 Case 3:Combined with measurement of horizontal angles

	ΔX(m)	ΔY(m)	ΔZ(m)	Δl(sec)
Max. Error	0.013	0.032	0.305	
Mean Error	0.007	0.011	0.106	3.6

Table 3-9 Case 4: Combined With measurement of horizontal angles with height apporoximates

	ΔX(m)	ΔY(m)	ΔZ(m)	Δl(sec)
Max. Error	0.013	0.032	0.034	
Mean Error	0.007	0.011	0.019	3.6

Table 3-10 Evaluation of the accuracy with use of GPS

Criteria 1 : within ±10 m

Given Random Error	Mean Error of Camera Station			
	1 m	5 m	10m	50m
5 cm	I II III IV	I II III IV	I II III IV	III IV
1 m	II III IV	II III IV	II III IV	III IV
5 m	IV	IV		
10m	IV			
50m				

Criteria 2 : within ± 5 m

Given Random Error	Mean Error of Camera Station			
	1 m	5 m	10m	50m
5 cm	I II III IV	I III IV	I III IV	III IV
1 m	IV	IV		
5 m	IV			
10m				
50m				

Criteria 3 : within ± 1 m

Given Random Error	Mean Error of Camera Station			
	1 m	5 m	10m	50m
5 cm	I III IV	III IV	III IV	III IV
1 m				
5 m				
10m				
50m				

Table 5-1 Categories of the MSA

Category	Type of Control	Number of Control Points	Number of Unknowns	Number of Observations	Geodetic survey Distance	Height	Angles	Station
	X, Y, Z	3	21	23	○			
I	X, Y, Z	3	21	29			○	
	X, Y, Z	2	21	23	○	○		
(Radial)	0, 0, 0	1	17	19	○	○		
	X, Y, Z	3	18	21	○			
II	X, Y, Z	2	18	20	○	○		
(Chain)	0, 0, 0	1	14	16	○	○		
	X, Y	4	18	Over 19	○			
III	X, Y	4	18	Over 19	○	○		
(GPS)	X, Y	4	18	21	○			○
IV	0, 0, 0*	4	14	18	○			
(Ruler)	0, 0, 0**	4	14	18	○	○		

where, ○ ; required measurement
0, 0, 0 ; arbitary data will be given
* ; Two ruler are placed almost on the same horizon plane
** ; Two ruler are not placed horizontally

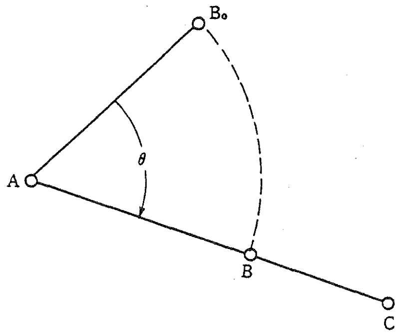


Fig. 2-1 Linearity

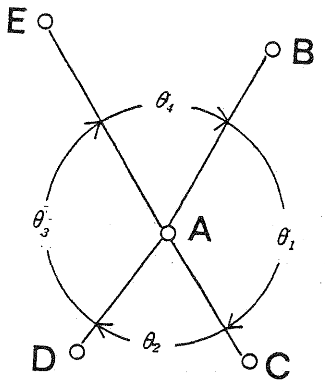


Fig. 2-2 Horizontal angles in clockwise

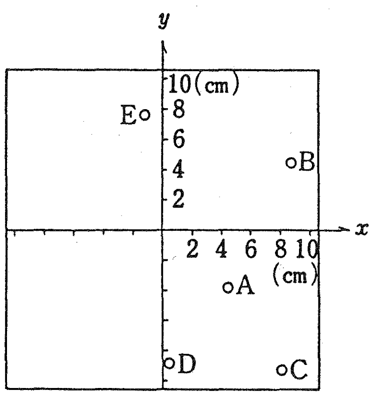
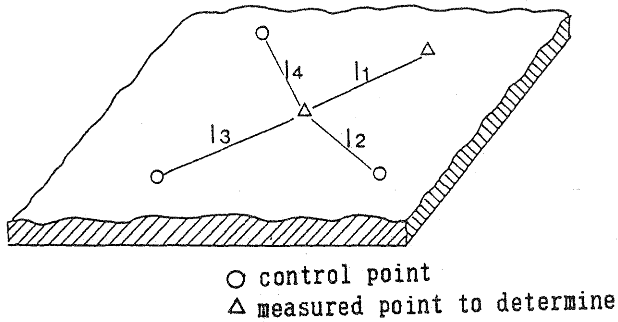
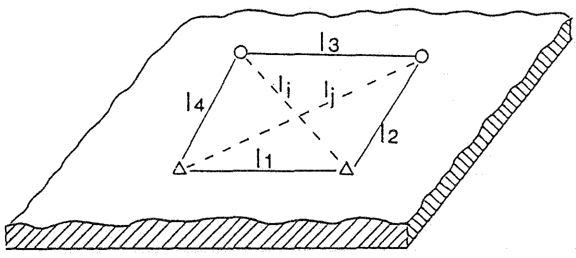


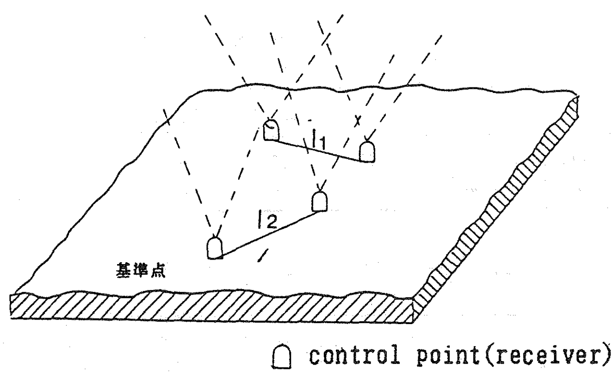
Fig. 3-1 Control points on a sigle film



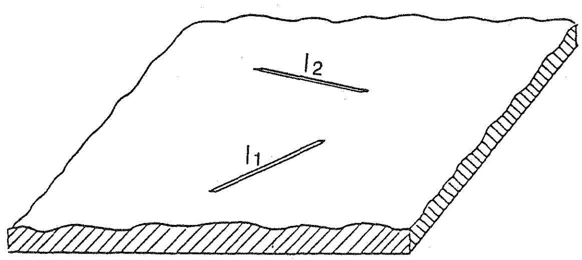
Category Ⅰ Radial type



Category Ⅱ Chain type

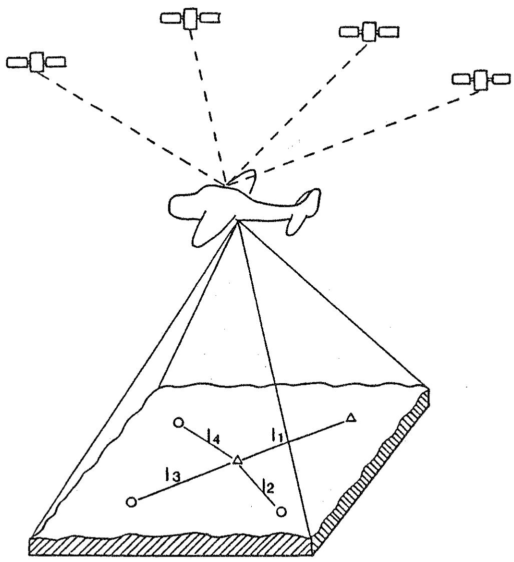


Category Ⅲ GPS type

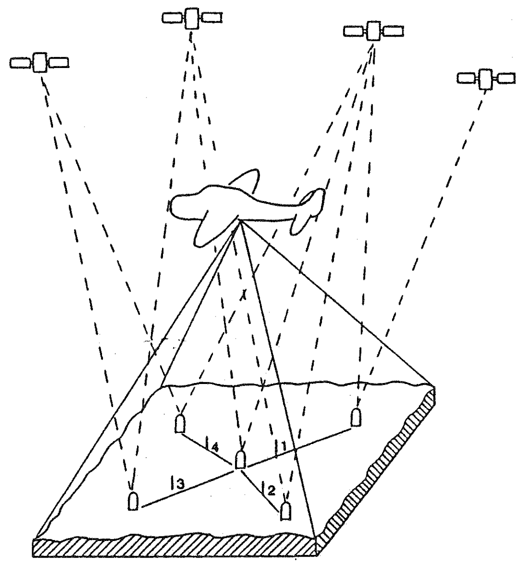


Category Ⅳ Ruler type

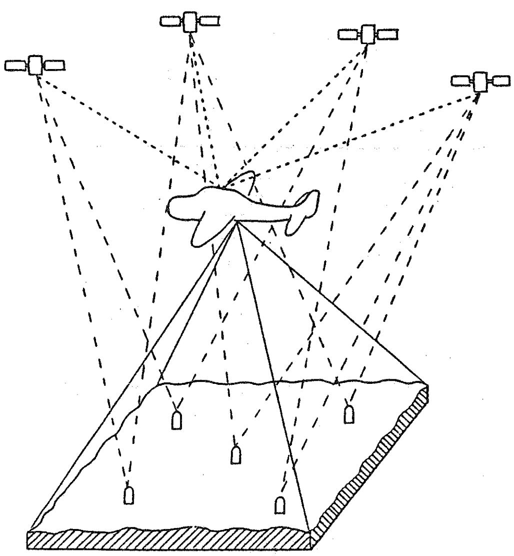
Fig. 5-1 Categories of the MSA



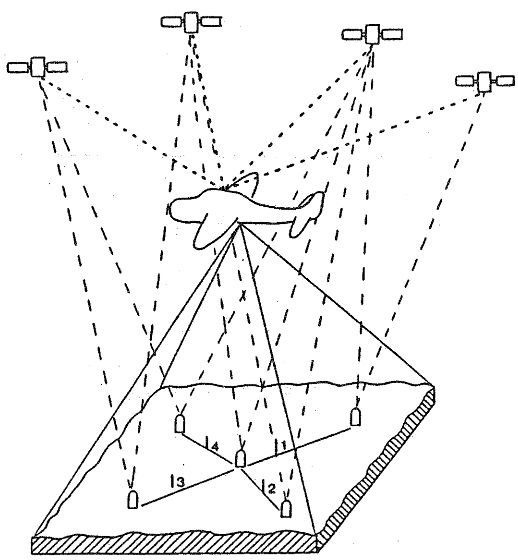
Type I Camera Station is given



Type III Distances and ground coordinates are given

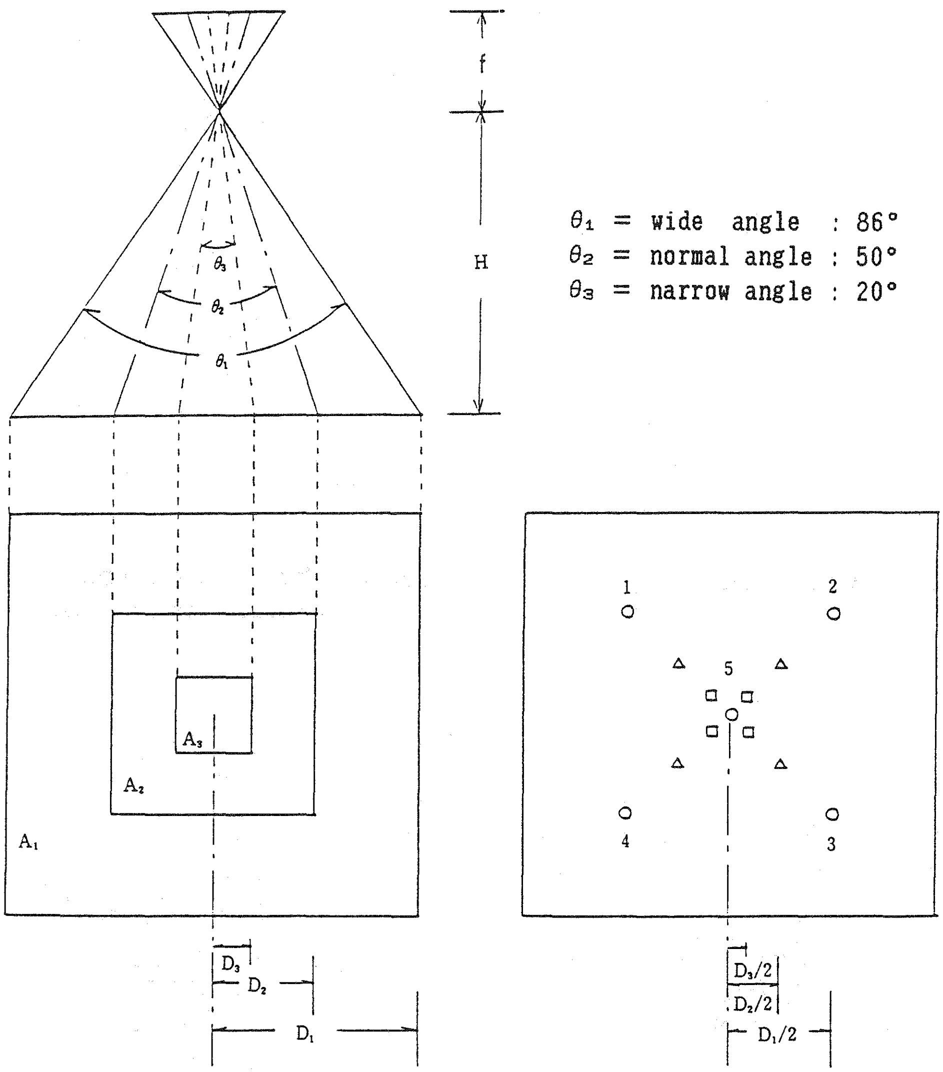


Type II Camera Station and ground coordinates are given



Type IV Camera Station, distances and ground coordinates are given

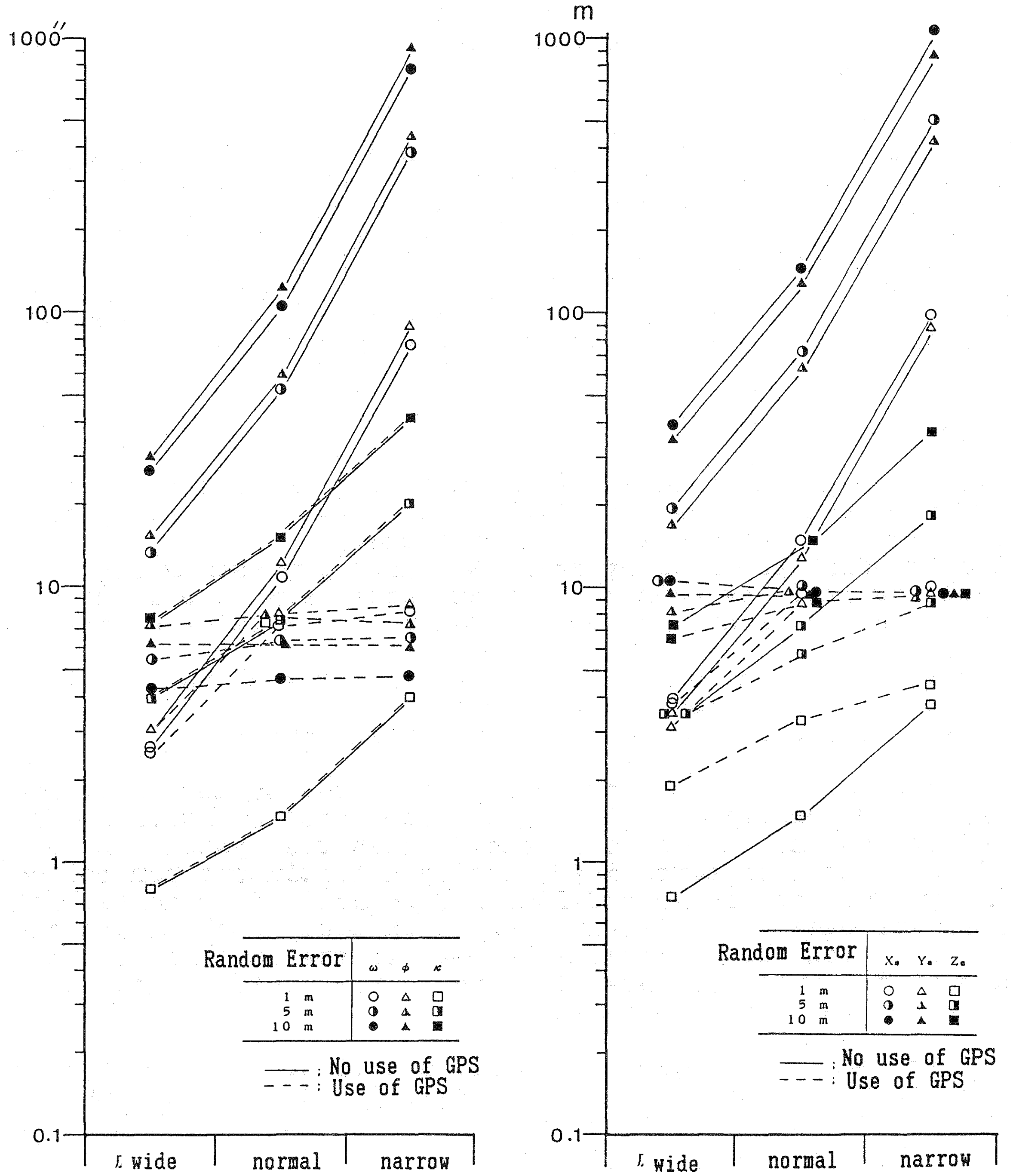
Fig. 3-2 Combined with measurement by GPS



(a) Coverage and angle

(b) Location of Control Points

Fig. 4-1 Simulation test model for space photogrammetry



(a) Accuracy of rotation angles (ω, ϕ, κ)

(b) Accuracy of shifting parameters (X_0, Y_0, Z_0)

Fig. 4-2 Accuracy of Orientation Parameters with respect to FOV and accuracy of control points (Positioning error of camera station = ±10m)