ACCURACY IMPROVEMENT OF THREE DIMENSIONAL POSITIONING USING SPOT IMAGERY

* YEU, BOCK-MO   * LEE, HYUN-JIK   ** SOHN, DUK-JAE

* DEPARTMENT OF CIVIL ENGINEERING YONSEI UNIVERSITY, SEOUL, KOREA
** DEPARTMENT OF CIVIL ENGINEERING SEONAM UNIVERSITY, NAMWON, KOREA
COMMISSION IV/2

ABSTRACT

This study aims to improve the accuracy of three dimensional positioning of SPOT imagery through 1)analysis of the optimum polynomial of exterior orientation for each preprocessing level, 2)through introduction of AP's(additional parameters) in the geometric adjustment of image distortion and 3)through elimination of gross errors in input data.

Optimal exterior orientation polynomial for each preprocessing level(1B; 15 parameters, 1AP and 1A; 12 parameters) was determined as a result of this study. Also, as a result of studying the accuracy of level 1A it was found that in case of accurate GCPs(ground control points), self calibration(significance testing) bundle adjustment with significant AP's is sufficient, whereas in case of inaccurate GCPs, simultaneous adjustment of bundle adjustment with gross error detection is advisable.

KEYWORD : SPOT imagery, optimal exterior orientation polynomial, 3-D positioning, simultaneous adjustment

1. INTRODUCTION

SPOT imagery has stable orbit characteristics, high resolution, suitable B/H ratio as well as off nadir viewing capabilities which makes stereo imagery possible. These characteristics makes SPOT imagery applicable in many fields such as agriculture, fishery, oceanography, environment studies and geology. Small scale topographic mapping and positioning of inaccessible areas are also made possible.

Factors influencing the accuracy of positioning using the SPOT imagery include data format, preprocessing level, exterior orientation estimation method, accuracy of GCPs and method of adjustment. But it would be difficult to take all these factors into account in adjustment. Therefore a phased analysis of these factors were made in an effort to improve the positioning accuracy.

The exterior orientation expressed as a function of the number of scanned lines and different photogrammetric film (level 1B and 1AP) and digital data(1A) of the same area were used in this study. The optimal exterior orientation polynomial and the suitable preprocessing level were determined through analysis of these data. Also, in cases of inaccessible areas simultaneous adjustment method with gross error detection and elimination was applied to the self calibration bundle adjustment method.

2. THEORY OF SIMULTANEOUS ADJUSTMENT OF SPOT IMAGERY

The theory of SPOT imagery positioning is applicable by making appropriate changes to the bundle adjustment, used mostly in analytical photogrammetry. The geometric stability of SPOT satellite makes it possible to consider the image geometry of the HRV sensor and the orbital parameters.

$$F(x)=x_i-x_p-f\,\frac{m_{11}(X_i-\bar{X}_{oi})+m_{12}(Y_i-\bar{Y}_{oi})+m_{13}(Z_i-\bar{Z}_{oi})}{m_{31}(X_i-\bar{X}_{oi})+m_{32}(Y_i-\bar{Y}_{oi})+m_{33}(Z_i-\bar{Z}_{oi})}+\Delta x_i=0$$

$$F(y)=0-y_p-f\,\frac{m_{21}(X_i-\bar{X}_{oi})+m_{22}(Y_i-\bar{Y}_{oi})+m_{23}(Z_i-\bar{Z}_{oi})}{m_{31}(X_i-\bar{X}_{oi})+m_{32}(Y_i-\bar{Y}_{oi})+m_{33}(Z_i-\bar{Z}_{oi})}+\Delta y_i=0 \qquad (1)$$

The estimation of the exterior orientation, the position ($\bar{X}_{oi}$, $\bar{Y}_{oi}$, $\bar{Z}_{oi}$) and attribute(κ_i, ϕ_i, ω_i) of the satellite, was carried out by applying the polynomial of second order of scanned lines. This was then changed to apply in the determination of optimal polynomial for exterior orientation for each preprocessing level.

$$\left.\begin{aligned}
\kappa_{oi} &= \kappa_o + K_1\,y + K_7\,y^2\\
\phi_{oi} &= \phi_o + K_2\,y + K_8\,y^2\\
\omega_{oi} &= \omega_o + K_3\,y + K_9\,y^2\\
\bar{X}_{oi} &= X_o + K_4\,y + K_{10}\,y^2\\
\bar{Y}_{oi} &= Y_o + K_5\,y + K_{11}\,y^2\\
\bar{Z}_{oi} &= Z_o + K_6\,y + K_{12}\,y^2
\end{aligned}\right] \qquad (2)$$

The accuracy of input data and the adjustment method used are also important factors in the approximation of exterior orientation, and the data format changes for different areas. It is therefore necessary adjust the random error as well as the systematic and gross error in a systematic and a rational way.

2.1 Introduction of AP's

The AP's have different error characteristics according to the selected earth ellipsoid, the preprocessing level and the data format. The AP's not only improves the positioning accuracy but also contributes to the detection and elimination of gross errors. Care should be taken in the selection of the AP's because inappropriate selection could result in an unstable adjustment and degrading of the accuracy.

It is effective to use the simultaneous adjustment with AP's which makes a simultaneous adjustment of all the observation errors. During this process, it is important that only effective parameters be selected and the significance testing of parameters be logically organized.

To correct all geometric distortion of imagery, a 3rd order polynomial of 18 variables was selected as the AP's. The selected parameters are as follows.

$$\begin{aligned}
\Delta x&=a_1+a_2x+a_3y+a_7\,x^2+a_8\,xy+a_9\,y^2+a_{13}x^3+a_{14}x^2y+a_{15}xy^2\\
\Delta y&=a_4+a_5x+a_6y+a_{10}x^2+a_{11}xy+a_{12}y^2+a_{16}x^3+a_{17}x^2y+a_{18}xy^2
\end{aligned} \qquad (3)$$

Equation (1) and (3) were applied in the geometric model and as can be seen in Fig. 1, only significant AP's were selected after correlaton analysis of all unknown variables and after significance testing of AP's.

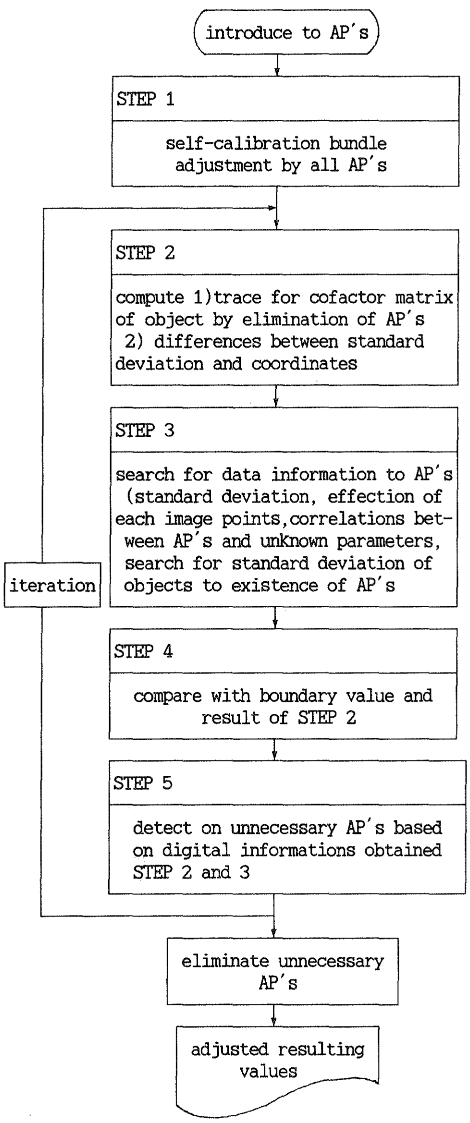


Fig. 1 determinability test of AP's

2.2 Detection and Elimination of Gross Errors

The conventional data snooping method is inefficient in cases where more than one gross error exist, for many iterations are needed for such cases. In this study the progressive data snooping method was applied which detects and eliminates gross errors in a continuous way. The results are updated as shown and during adjustment of gross errors, only observations with errors will be used together with the formerly adjusted value. The progressive data snooping method used in this study is as in Fig. 2.

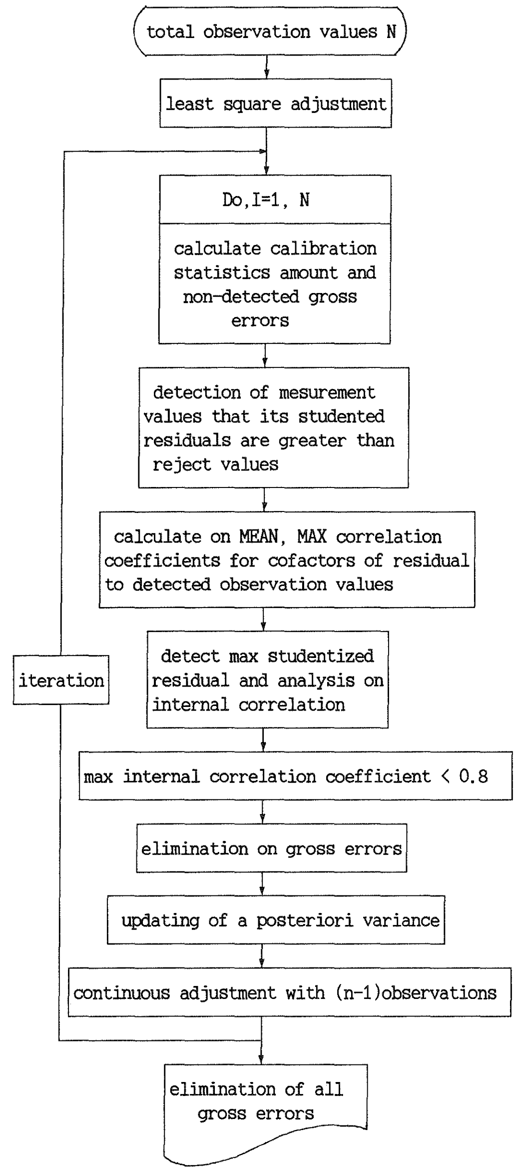


Fig. 2 flow of progressive data snooping method

3. ANALYSIS OF OBSERVATIONS

3.1 Characteristics of Satellite Imagery and Formation of Input Data

The satellite imageries used in this study are images of the same area aquired from different orbits and preprocessed in level 1B and level 1AP (photogrammetric films) and 1A (digital format in CCT). All satellite data are in panchromatic mode and the left image is vertical (L5°37′) and the right image is oblique (R26°10′). Stereo model is formed as in Fig. 3.

The base to height ratio is about 0.57 and the time difference between the left image (87.11.29) and the right image (87.11.30) is about a day, which means small difference of sun view angle which gives favorable observation conditions.

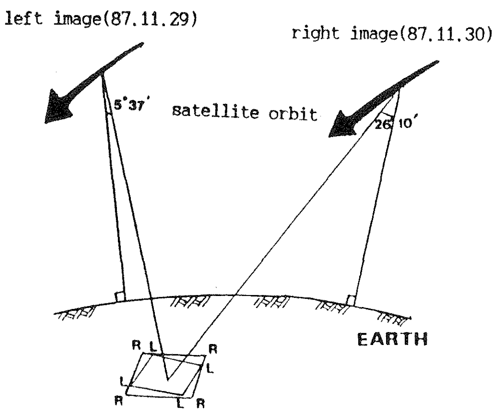


Fig. 3 stereo model of satellite images

table 1. major characteristic of SPOT photogrammetric film

major	level 1B		level 1AP	
characteristic	left	right	left	right
x(mm)	150.0	182.8	173.0	210.0
y(mm)	150.0	150.0	171.4	171.4
scale	1/400,000		1/350,000	
focal length	2072.0(mm)		2370.5(mm)	
1 pixel size	0.0250(mm)		0.0285(mm)	

The total amount of control points used is 23 and 13 of these are GCPs and 10 are check points. The distribution of the GCPs is as in Fig. 4.

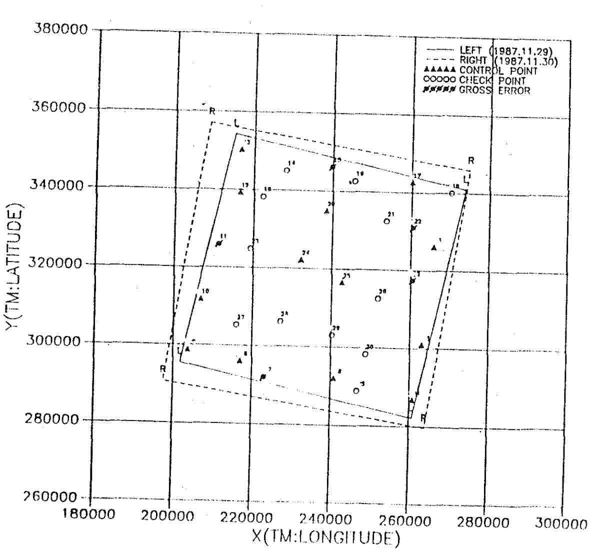


Fig. 4 distribution of GCPs

The GCPs coordinates were acquired by ground survey and from 1:50,000 topographic maps. Image coordinates were acquired using the Zeiss P2 Planicomp for level 1B and 1AP. For digital imagery level 1A, LINE/PIXEL of GCPs were observed in subpixel units through image processing methods. Initial values for the position of satellite position were interpolated from the header data and exterior orientation and polynomial coefficients were approximated and satellite height was adjusted considering the earth curvature. Also, for the initial value for the orientation of satellite, image orientation(γ) was used as κ_0, inclined angle of the sensor was used as ϕ_0, and ω_0 was set to 0^0.

3.2 Determination of optimal polynomial for exterior orientation for each preprocessing level

The approximation of dynamic exterior orientation of SPOT imagery is an important factor influencing the reliability and accuracy of adjustment system and is also an essential process in the establishment of DEM's and in the production of orthophotos.

In this study, varied forms of equation (2) as shown in table 2, were used to determine the optimal polynomial of exterior orientation for each proprocessing level(table 2).

table 2. analysis case for optimum polynomial of E.O.P. (exterior orientation parameters)

case	NO. of E.O.P.	parameters	remarks
1	12	$X_o, Y_o, Z_o, \kappa_o, \phi_o, \omega_o$, $K_1y, K_2y, K_3y, K_4y, K_6y$	1st order:position 1st order:attribute
2	15	case1+$K_{10}y^2, K_{11}y^2, K_{12}y^2$	2nd order:position 1st order:attribute
3	15	case1+K_7y^2, K_8y^2, K_9y^2	1st order:position 2nd order:attribute
4	18	case1+$K_7y^2, K_8y^2, K_9y^2, K_{10}y^2$, $K_{11}y^2, K_{12}y^2$	2nd order:position 2nd order:attribute

The input data for GCPs were acquired through ground surveying and for image coordinates were acquired using the analytical plotters(leve 1B and level 1AP) and using the GCP module of the ERDAS image processing package in subpixel units(level 1A). The result of adjustment for each case according to each preprocessing level is in table 3.

It can be seen from the table that for level 1B, a 15 parameter polynomial is the optimal polynomial, where first order for satellite position and second order function of scanned lines are applied. For level 1AP and 1A, 12 parameter polynomial with first order function of scanned lines is optimal.

Also, to analyse the the 3-D positioning accuracy of each preprocessing level, bundle adjustment was carried out for each case with the optimal polynomial.(table 4, Fig. 5) table 3. adjustment results of analysis case with preprocessing (unit : m)

case		1			2			3			4		
order		position:1st attitude:1st			position:2nd attitude:1st			position:1st attitude:2nd			position:2nd attitude:2nd		
pre-pro cessing		1B	1AP	1A	1B	1AP	1A	1B	1AP	1A	1B	1AP	1A
precision	σ_x	10.50	7.18	10.49	9.59	8.25	12.19	9.39	13.02	11.19	10.93	12.33	12.88
	σ_y	11.71	6.97	10.17	10.90	8.01	11.92	10.57	12.34	10.94	11.50	11.55	12.34
	σ_{xy}	11.21	7.08	10.33	10.27	8.13	12.06	10.00	12.68	11.07	11.17	11.95	12.61
	σ_z	20.90	12.02	15.00	18.89	16.73	17.43	18.42	26.42	16.00	19.89	25.26	21.23
accuracy	μ_x	18.00	11.18	13.31	17.17	12.24	13.85	17.71	20.70	13.88	16.98	15.05	16.96
	μ_y	14.26	8.91	7.44	14.36	11.17	8.29	9.12	10.77	9.00	9.89	25.57	10.94
	μ_{xy}	16.24	10.11	10.79	15.83	11.72	11.41	14.02	16.50	11.70	13.90	20.98	14.25
	μ_z	17.00	11.30	6.42	16.36	18.14	7.01	13.77	20.51	7.00	20.51	17.07	12.67
image coordinates residual	V_x (mm)	0.0281	0.0217	0.0153	0.0270	0.0261	0.0177	0.0262	0.0224	0.0177	0.0224	0.0270	0.0156
	V_y (mm)	0.0260	0.0181	0.0163	0.0245	0.0206	0.0168	0.0238	0.0174	0.0461	0.0370	0.0370	0.0149

table 4. 3-D positioning accuracy with preprocessing

E. O. P.	pre-processing	geometric precision (m)		accuracy of check point (m)		image coordinate residual(pixel)	
		σ_{xy}	σ_z	μ_{xy}	μ_z	V_x	V_y
15	1B	10.00	18.42	14.02	13.77	1.048	0.952
12	1AP	7.08	12.02	10.11	11.30	0.761	0.635
12	1A	10.33	15.00	10.79	6.42	1.177	1.253

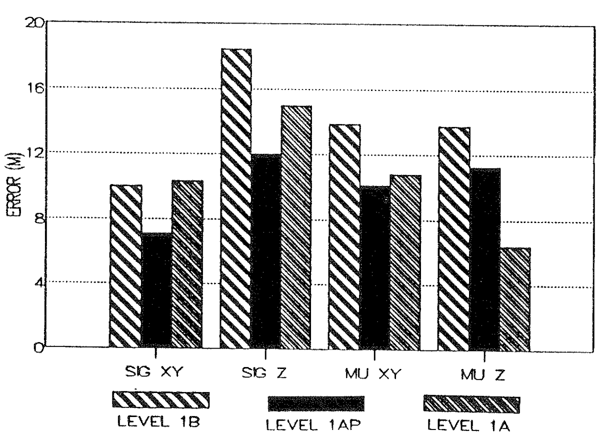


Fig. 5 3-D positioning accuracy with preprocessing

It was found through this analysis, that for photogrammteric film products level 1AP is more suitable compared to 1B for positioning due to its geometric stability. It was also found that level 1AP showed better accuracy compared to 1A, according to the difficulty in acquiring the image coordinates. But when considering that level 1AP requires analytical plotters, if methods to improve the image coordinates accuracy of level 1A is used, it can be said that level 1A image data is the suitable data format for middle and small scale map production as well as for establishment of large topographic database.

3.3 Analysis of 3-D Positioning Accuracy According to Adjustment Method

In this study, to design a logical adjustment system for positioning, AP's were introduced to polynomial such as equation (3). Also, a simultaneous adjustment method for detection and elimination of gross errors was developed and this was used in studying the effect of using different adjustment methods. The significance testing which determines significant AP's was included in the developed simultaneous adjustment method.

For comparing accuracies according to adjustment method, two cases were studied. Case 1 is level 1AP with ground surveyed controls and case 2 is level 1A with GCP from 1:50,000 maps. For the case of level 1A with GCP from 1:50,000 map(case 2), it was done to represent cases where mapping has to be carried out for inaccessible area.(table 5)

table 5 accuracy of analytic case with adjustment analysis method

case	preprocessing levels	data type	aquisition method of G.C.P.	
			3-D coordinate	image coordinate
1	1AP	photogrammetric film	ground survey	analytic plotter
2	1A	digital image	1:50,000 map	eye measurement

3.3.1 Accuracy Analysis with AP's

For this analysis, a self calibration bundle adjustment with 18 AP's which includes signicance testing was used(Table 6, Fig. 6).

For case 1, after adjustment with significant AP's and geometric correction, the geometric precision and accuracy of check points improved uniformly to less than 10 M.

table 6. accuracy analysis with AP's

(unit:m)

case	without AP's				with AP's			
	σxy	σz	μxy	μz	σxy	σz	μxy	σz
1	7.08	12.02	10.11	11.30	6.22	9.81	8.97	9.48
accuracy increasing rate(%)					12.15	18.34	11.28	16.11
2	16.63	36.14	38.29	26.09	16.59	31.48	38.05	20.62
accuracy increasing rate(%)					0.2	12.9	3.2	20.9

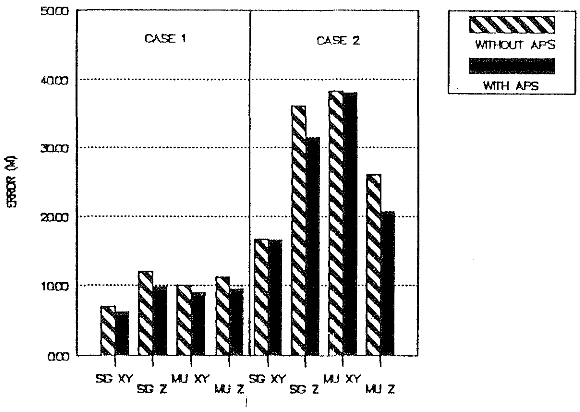
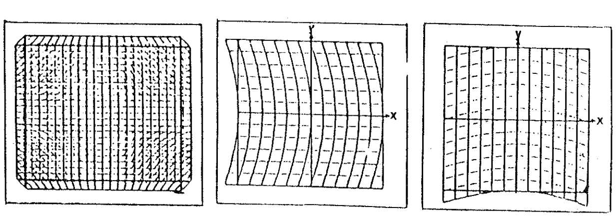


Fig. 6 accuracy analysis with AP's

But, for case 2 where accuracy of GCPs are relatively low, height accuracy was improved by 10% but for planimetric accuracy the improvement was less than 5% due to influence of gross errors. High accuracy improvement cannot be expected with only AP's in case 2.

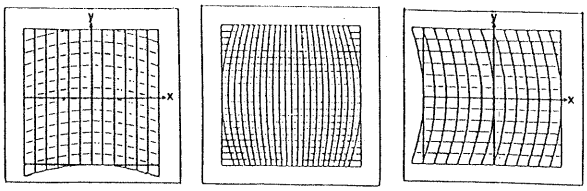
Therefore in cases where gross errors are present in GCPs, simultaneous adjustment method with AP's and gross errors elimination process is necessary to compensate for the error of GCPs.

The developed self calibration bundle adjustment program includes the significance testing process. The significance testing process corrects systematic influence of the AP's for the whole adjustment system through the F test which is a multi-dimensional test. Then AP's after the multi-dimensional test are gone through the one dimensional t test. These processes determines the AP's which are significance of the level 1AP photogrammetric film and the level 1A digital images(Fig. 7).



$\Delta x = a_2 x$ $\Delta x = a_9 y^2$ $\Delta y = a_{10} x^2$

(a) level 1AP



$\Delta x = a_7 x^2$ $\Delta x = a_{15} xy^2$ $\Delta x = a_9 y^2$

(b) level 1A

Fig. 7 effects of significant AP's determinated from this study

3.3.2 Accuracy Analysis According to Gross Errors Elimination

In the elimination process of gross errors, after confirming the presence of gross errors from residuals of image coordinates computed by self calibration bundle adjustment of cases in table 7, simultaneous adjustment with progressive gross error elimination method was applied.

The determined studentized residual ti and the Baarda test statistics amount $t_i > 4.13\sigma_0$ was used which suggests the minimum power of test $(1-\beta)$ to be 80% at 0.1% significance level.

No gross error was detected for case 1, but for case 2 where the ground control points and image coordinates are geometrically unstable, gross errors were detected for points no.22 and no.27. The result of simultaneous adjustment of case 2 is in table 7 and the accuracy improvement due to AP's and to gross error elimination is as in Fig. 8.

table 7 accuracy of 3-D coordinate with elimination of gross errors

(unit:m)

item	geometric precision		accuracy of check point		remarks
	σxy	σz	μxy	μz	
bundle adjustment	16.63	36.14	38.29	26.09	
self calibration bundle adjustment	16.59	31.48	38.05	20.62	AP a_7, a_{15}, a_{16} regarded
increasing rates of accuracy(%)	0.2	12.9	3.2	20.9	
simultaneous adjustment	14.28	26.97	28.33	15.30	AP a_7, a_{15}, a_{16} and elimination of gross error NO.22,27
increasing rates of accuracy(%)	14.1	25.4	27.9	41.4	

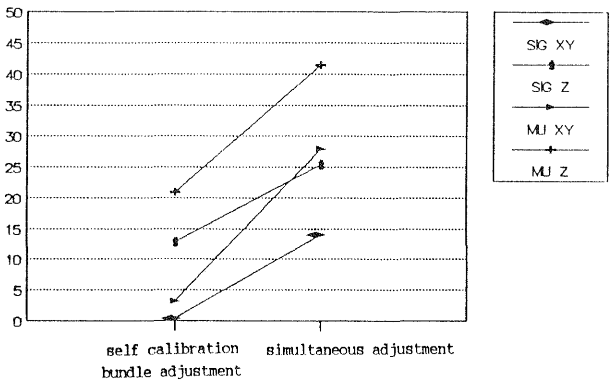


Fig. 8 increasing rates of accuracy by simultaneous adjustment

For case 2, simultaneous adjustment showed improved geometric precision and improved accuracy of check points.

It was shown in this study that, only significant AP's are sufficient to improve accuracy for cases where accurate GCPs are used, but for cases where this is not possible such as inaccessible areas, a simultaneous adjustment method is necessary which uses gross errors elimination method added to the self calibration bundle adjustment method with AP's.

4. CONCLUSION

The followings can be concluded from this study which studied the accuracy improvement methods of three dimensional positioning using the SPOT imagery.

1. The optimal exterior orientation polynomial for each preprocessing level was determined through analysis of various exterior orientation polynomial which is shown as a function of the number of scanned lines.

2. Analysis of 1AP photographs with accurate ground controls with the developed self calibration bundle adjustment program, showed accuracy of less than 10 M in both planimetry and height, a validation of this program.

3. For inaccessible areas where accurate GCPs are difficult to get, self calibration bundle adjustment could not improve the accuracy as much as the simultaneous adjustment which combines the gross errors detection and elimination method to the self calibration adjustment.

Appreciation is showd to ADD(Agency for Defense Development) which has funded this study(UD900013).

REFERENCE

1. Dowman,I.J. & D.J.Gugan, 1988, "Application Potential of SPOT Imagery for Topographical Mapping " , Advanced Space Research, 5(5).
2. Kratky, V., 1989, " Rigorous Photogrammetric Processing of SPOT Images at CCM Canada ", ISPRS Journal of Photogrammetry and Remote Sensing, Vol.44.
3. Rodriguez, V. , P.Gigord , A.C.de Gaujac & P.Munier, 1988, " Evaluation of the Stereoscopic Accuracy of the SPOT Satellite", P.E. & R.S.,Vol. 54, No. 2.
4. ZEISS,1987,SPOT-Bundle Adjustment Program for Engineering Objects and Restitution of SPOT Images, ZEISS Oberkochen.
5. Konecny, G., P. Lohmann & E. Krück, 1987, " Evaluation of SPOT Imagery on Analytical Photogrammetric Instruments ", P.E.& R.S., Vol.53, No. 9.
6. Gugan, D.J. & I. J. Dowman, 1988, " Accuracy Completeness of Topographic Mapping from SPOT Imagery " , Photogrammetric Record, 12(72).
7. Kratky V.,1988, " Universal Photogrammetric Approach to Geometric Processing of SPOT Images ",ISPRS, Commision IV, Vol. 27.
8. Kratky,V.,1989, "On Line Aspects of Stereophotogrammetric Processing of SPOT Images", P.E. & R.S., Vol. 55, No. 3.
9. Yeu, Bock Mo., Lee, Hyun Jik., 1991, "A study on analysis of accuracy of SPOT satellite image with preprocessing levels",Journal of Korean Society of Goedesy, Photogrammetry, and Cartography, Vol.9, No.1, pp.83-96.
10. Agency for Defence Development, 1990, 1991, A Study on the aquisition of exterior orientation parameter in SPOT imagery (I),(II), MSRD-408-90282.