Accuracy Evaluation by GCP Acquisition Method in Bundle Adjustment for SPOT Imagery

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ABSTRACT

This study looks into the positioning accuracy of SPOT imagery according to GCPs(ground control points) acquisition method used for different data format and for different land features.

Suitable GCP acquisition method is presented in this paper for different data format and the accuracy limit for each case is also presented. Through analysis of digital image coordinates, it was confirmed that the least squares method of adjustment is effective for accuracy improvement and for reducing the number of interation.

KEYWORD: GCP, inaccessible area, least square image matching

1. INTRODUCTION

3-D positioning of SPOT imagery can be divided into two different methods; using the analytical plotters and applying the bundle adjustment method, and using the digital image in the CCT and applying image processing methods. Both methods need precise ground coordinate and stereo image coordinate of GCPs.

SPOT images are mostly in small scales and the ratio of bandwidth to altitude is about 0.074. Therefore the error within GCPs influence to a great extend the accuracy of dynamic exterior orientation estimation and of the overall accuracy. This implies that care should be taken in the selection of GCPs to get acceptable results with SPOT images.

For inaccessible areas, because the image resolution can be better than the the map accuracy from which the 3-D coordinate of GCP are taken, a logical methodology for acquisition of GCP has to be established.

In this study, acquisition methods of GCP have been presented according to land features and data format. Also, acquisition method of GCP is suggested for inaccessible areas.

2. ACQUISITION METHODS OF GROUND CONTROL POINTS

2.1 Selection of Ground Control Points

The selection of GCPs depends on the planned accuracy, availability of selection, distribution of points and the number of points. The selection for GCPs will have to be decided by the availability of image coordinates.

First of all, clear features which could be clearly identified in both the stereo images were selected and then the image coordinates of these points as well as their ground coordinates were acquired.

The total number of ground controls selected in this study was 30 but due to changes in the topography maps, 7 were unable to be identified on the map, resulting in 23 points.

The GCPs were usually features exceeding 1 pixel, such as road crossings and intersections between roads and rivers.

2.2 3-D Coordinates of GCPs

Ground control points have to be determined according to land features and the planned accuracy. Methods for acquiring 3-D coordinates of ground control points include, ground surveying, using aerial photogrammetry and using maps. In this study 3-D coordinate of GCPs were picked from maps and these were controlled with ground surveyed coordinates.

2.2.1 Ground Surveying

Ground surveying produces accurate coordinates but has the disadvantage that it is expensive and that it is not possible to be applied to inaccessible areas.

A network was form linking to the National network and Wild T3 and Range Master II and DI-3000 were used for precise traverse surveying and triginometric leveling.

2.2.2 Photogrammetric Method

A lot of time of is necessary for adjustment and it is expensive to get ground controls coordinates and also cannot be used for inaccessible areas.

2.2.3 Using Maps

This method is applicable to inaccessible areas. This method is mostly widely used because it is inexpensive and effective. But there are some disadvantages such as in case of small scale maps problems can be anticipated when the image resolution is smaller than the map accuracy, and difficulty in identifying objects from outdated maps.

In this study, maps of scale 1:50,000(10 sh etc) and 1:25,000(28 sh etc) were used for acquiring 3-D coordinates of GCPs. Planimetric positions were acquired from observing digitized coordinates and height positions were acquired from weighted average interpolation(Fig. 1).
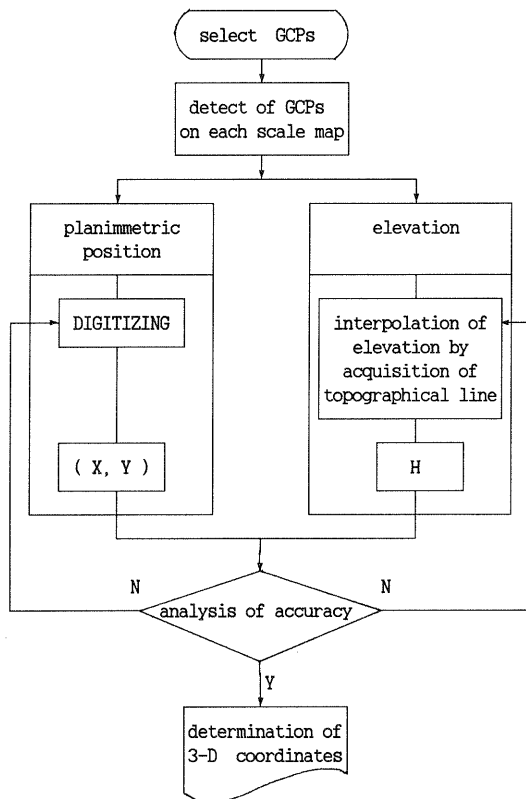
Fig 1 flow of acquisition of 3-D coordinates of GCPs by maps

(1) Planimetric Coordinates using Digitizer

In this method, the errors within the map itself poses a problem. The allowable standard error for planimetric coordinates is 0.5MM and for height the error should not exceed half of contour interval. There is no standard limit for error in digitizing but generally, it should not exceed half of cross mark size. Calcomp 9/480 (50 lines/mm) was used to digitize the selected points 10 times. These coordinates were affine transformed using 4 corners of the map.

(2) Height Coordinates using Interpolation Method

Height coordinates are derived from a map by using contour lines and spot heights for interpolation. A grid was superimposed with the ground control point in the middle and planimetric and height coordinates are derived for 8 directions. The selected points are usually crossroads which means that the area is usually plain. To overcome this problem weighted average interpolation was used as shown in Fig. 2.

In Fig. 2, the distance from the control point to the interpolated point is computed from the next equation.

$$D_i = \left\{ \frac{(X_i - X_o)}{D_x} \right\} + \left\{ \frac{(Y_i - Y_o)}{D_y} \right\} , \quad (i = 1, 2, \ldots, 8) \quad (1)$$
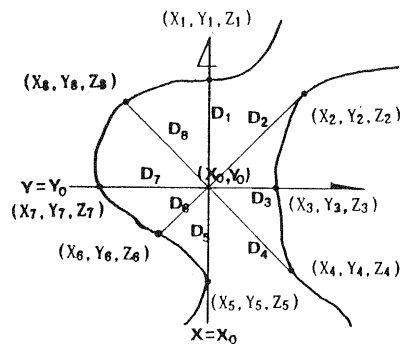

Fig. 2 interpolation of elevation by weighted average interpolation method

where (X_o, Y_o) is planimetric coordinate of GCP and (X_i, Y_i) is the relative planimetric coordinate of GCP in the 8 directions used for interploation and (D_x, D_y) is grid distance in X and Y direction. The height of ground controls can be computed to the next equation.

$$h(X_o, Y_o) = \frac{\Sigma W_i Z_i}{\Sigma W_i} \quad (2)$$

where, $W_i = 1/D_i$ and Z_i is height of data points.

The points used as GCPs are mostly intersections of roads, pathways and waterways. Different values of height are determined according to width of the road and scale of the map used. Special care should be taken in cases where width are small and the map scale is small because small roads tend to change quite often and the maps are not updated quite as often.

2.3 Image Coordinates of GCPs

It is difficult to get image coordinates of selected GCPs from the small scaled SPOT images. The image coordinates acquisition method varies with data formats. For photogrammetric data(level 1AP) expensive analytical plotters are necessary whereas for digital data(level 1A) the image coordinates can be acquired through image processing methods using computers.

2.3.1 Image Coordinates Of Photogrammetric Film

For level 1AP images the image coordinates are observed through analytical plotter after orientation of the stereo model. It can also be done using a comparator, which can observe each stereo pair separately.

In this study, level 1AP images were observed in the Zeiss P2 analytical plotter. The observed coordinates are tranformed to image coordinates with the affine transformation.

2.3.2 Image Coordinates of Digital Image

There are three methods for observation of image coordinates of digital images; observation with the eye, digital image (DCM) correlation method and least squares image matching method(LSM).

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The above mentioned three methods were applied to level 1A digital images. For observation of image coordinates, ERDAS an image processing system package was used. The flow for digital image correlation and least squares image matching is as in Fig. 3. The line/pixel of the selected GCP's is transformed to the image coordinate system and used in the analysis of results.

table 1. principles of SPOT satellite image data

(WGS 84 geodetic coordinate)

	left image	right image
satellite identification	SPOT 1	SPOT 1
sensor identification	HRV 2	HRV 1
GRS designator	305/277	305/277
preprocessing level	1A	1A
spectral mode	PAN	PAN
scene center location (C$_0$)	N 36°22′02″ E127°25′41″	N 36°22′02″ E127°25′08″
location of nadir of satellite when center line is scanned	N 36°32′25″ E126°39′07″	N 35°53′04″ E131°19′48″
satellite altitude	829875.9	829741.3
angle of incidence (α)	L 5°37′	R26°10′
scene orientation angle	11°23′29″	8°13′42″
scene acquisition date	1987.11.29	1987.11.30
coding mode	DPCM BIL	DPCM BIL

The area is between N36°02′ ~ N36°41′ and E127°02′ ~ E127°50′ which is an area around Chungnam and Chungbuk. The area is about 60 km x 60 km and as in Fig. 4.
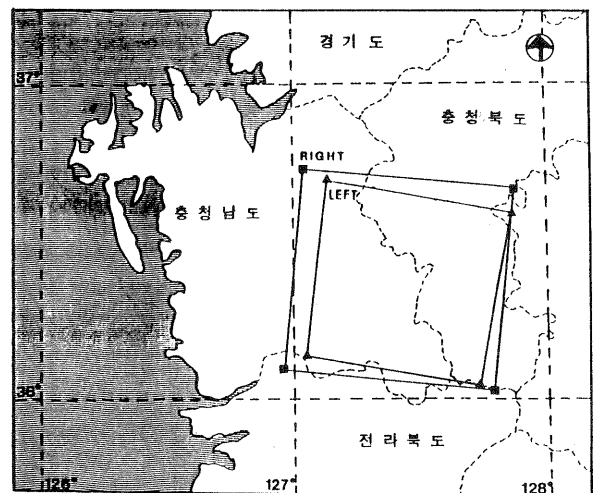
Fig. 4 study area and scene distribution type

4. ANALYSIS OF OBSERVATION VALUES

In the analysis of observation values, the accuracy limit of the acquired GCPs, picked from map, were analysed. Next, accuracy analysis with the data format, preprocessing level and the GCP acquisition methods were taken into account. Also various methods for acquiring image data from digital image were analysed.
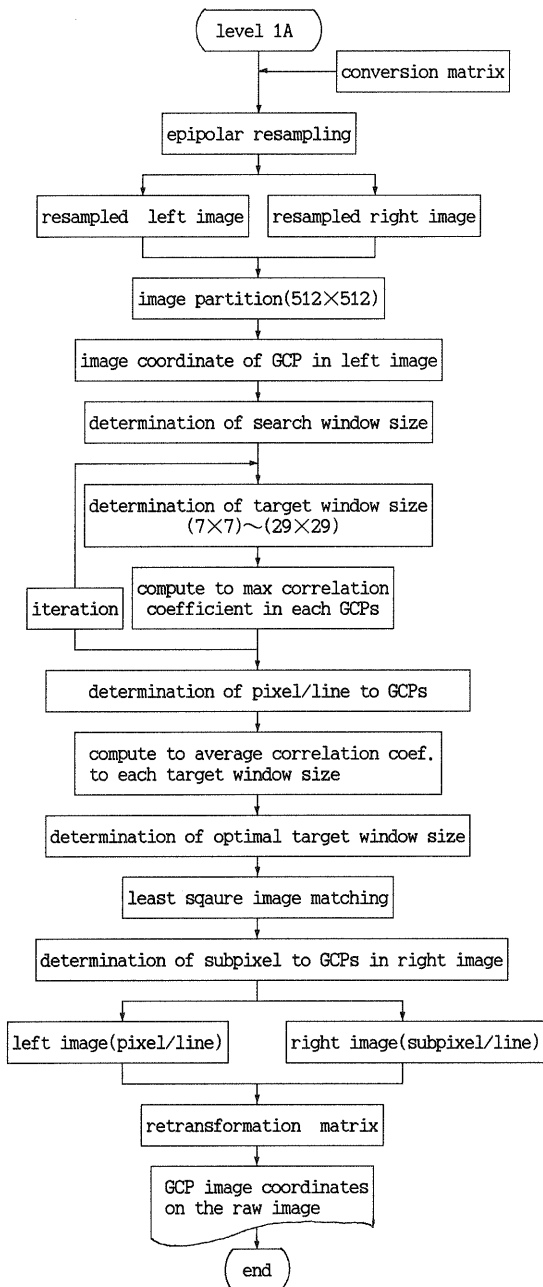

Fig. 3 acquisition of image coordinate of GCPs by image matching

3. DATA FORMAT AND LAND FEATURES

The image formats used in this study is level 1AP photo image and level 1A digital image of the same area. Characteristics of the image used in this study is as in table 1.

4.1 Error Analysis According to of 3-D Coordinates Acquisition Method of GCPs

In the error analysis of GCPs, coordinates obtained by ground surveying were considered as true values and these were compared with coordinates obtained from maps of 1:25,000 1:50,000. The results are as in table 2.

table 2. standard deviations of 3-D coordinates to GCPs in each scale maps

(unit:m)

standard dev. scale	σ_x	σ_y	σ_{xy}	σ_z
1:25,000	12.62	11.78	12.21	2.67
1:50,000	27.81	25.79	26.82	5.64

It was found that the planimetric error of more than 1 pixel, 10M, occured in all scales. In cases where 1:50,000 maps were used, errors more than 2 pixels occured. Therefore gross error detection and elimination adjustment method could prove to be effective. Height accuracy proved to be acceptable which implies that the interpolation method used is an effective method.

4.2 Accuracy Analysis of According to GCP Acquisition Methods

In this analysis, the acquisition method in this study and the image coordinates acquisition method were taken into account(table 3).

table 3. accuracy analysis case of 3-D coordinates with method of GCPs acquisition

case	pre-processing level	GCP acquisition methods		data type
		3-D coordinates	image coordinates	
1	1AP	ground surveying	method by	satellite
2	1AP	1:25,000 map	analytic	
3	1AP	1:50,000 map	plotter	photo
4	1A	ground surveying	eye measurement by	digital
5	1A	1:25,000 map		
6	1A	1:50,000 map	image processing	iamge

For each case, optimal polynomial for exterior orientation(12 variables) was used for each preprocessing level in the bundle adjustment. The geometric precision of adjustment result of each case, is determined by acquired data for GCPs and the check points accuracy is the difference from 3-D coordinates according to ground surveying(table 4, Fig. 5).
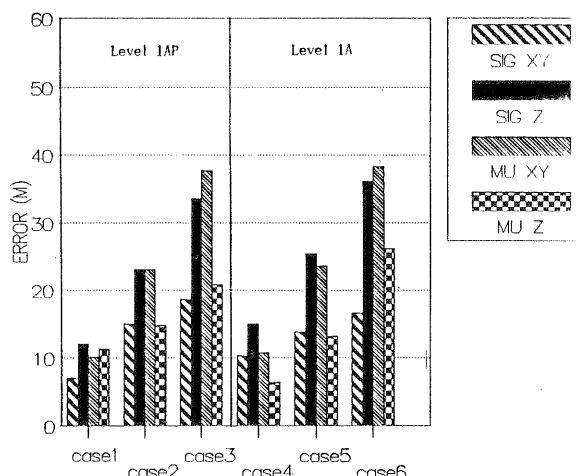

Fig. 5 accuracy of 3-D coordinates with method of GCPs acquisition

table 4. accuracy of 3-D coordinates with method of GCPs acquisition

(unit:m)

pre-processing level	analysis case	APs	geometric precision				accuracy of check point				residual of image coor.		No.of iterating calculation
			σ_x	σ_y	σ_{xy}	σ_z	μ_x	μ_y	μ_{xy}	μ_z	V_x pixel	V_y pixel	
1A	1	12	7.18	6.97	7.08	12.02	11.18	8.91	10.11	11.30	0.0217 0.7610	0.0181 0.6340	8
	2	12	15.30	14.68	15.00	23.09	26.17	19.53	23.09	14.83	0.0520 1.8220	0.0308 1.0790	16
	3	12	19.04	18.09	18.57	33.57	42.31	32.39	37.68	20.81	0.0758 2.6570	0.0299 1.0480	24
1AP	4	12	10.49	10.17	10.33	15.00	13.31	7.44	10.79	6.42	0.0153 1.1770	0.0163 1.2540	16
	5	12	14.27	13.52	13.90	25.37	26.85	23.63	14.02	13.20	0.0191 1.4690	0.0231 1.7770	23
	6	12	17.21	16.02	16.63	36.14	43.37	32.44	38.29	26.09	0.0259 1.9920	0.0212 1.6310	24

As result of analysis of acquisition method of GCPs, ground surveying method proved to be the best and in case of using maps as source of 3-D coordinate of GCP, accuracy fell for height. For check points, height proved to be better than planimetry. In case of using maps, case 2,3,5,6, height error proved to smaller than planimetric error. The residual for image coordinates proved to be large when maps were used for 3-D coordinates of GCPs, which makes increased iteration necessary. It can be seen that errors in image coordinates should be decreased and that adjustment methods should be developed to overcome the inaccuracy of GCPs. For this purpose, image correlation and least squares image matching methods were applied.

4.3 Accuracy analysis of According to Image Coordinates Acquisition Method

Level 1A images were used to get image coordinates through the eye measurement, through digital image correlation and through least squares image matching.

Bundle adjustment method was used to analysis acquisition methods for image coordinates (table 5, table 6, Fig 6).

table 5. accuracy analysis case of 3-D coordinates with method of GCPs acquisition

preprocessing	case	method of image coordinates acquisition	method of 3-D coordinates acquisition
1 A	1	eye measurement	ground surveying
	2		1:50,000 map
	3	correlation of digital images	ground surveying
	4		1:50,000 map
	5	least square image matching	ground surveying
	6		1:50,000 map

table 6. accuracy of 3-D coordinates with method of GCPs acquisition

(unit:m)

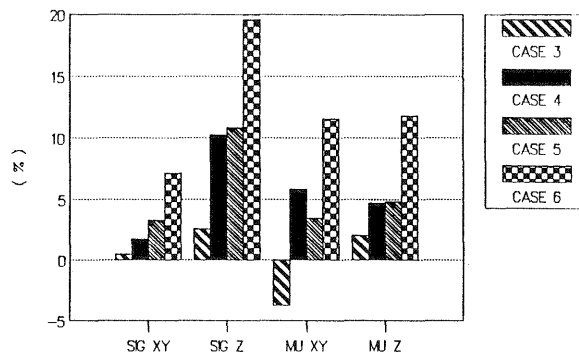| pre-proce ssing level	anal ysis case	geometric precision		accuracy of check point		residual of image coor.		No.of iter ating calcu lation
		σ_{xy}	σ_z	μ_{xy}	μ_z	V_x pixel	V_y pixel	
1A	1	10.33	15.00	10.79	6.42	1.177	1.254	16
	2	16.63	36.14	38.29	26.09	1.992	1.631	24
	3	10.28	14.62	11.19	6.29	1.023	0.971	11
	4	16.34	32.43	36.07	24.87	1.697	1.524	12
	5	9.99	13.37	10.42	6.11	0.925	0.781	10
	6	15.45	29.07	33.87	23.02	1.524	1.387	12

Fig. 6 increasing rate of positioning accuracy with method of image coordinate acquisition

As results of analysis, it was found that image correlation method is better than the naked eye mesurement method and the least sqres image matching method reduced the number of iteration and increased the positioning accuracy.

5. Conclusion

This study aims to analyse 3-D positioning according to ground control acquisition methods then to present optimal acquisition method for each data format and land features. The following points could be concluded.

Ground control acquisition methods for each data format and according to land features were determined as well as the accuracy limits.

Also, Through analysis of image coordination acquisition methods in digital imagers, it was found that image correlation and least squares image matching techniques reduced the number of iterations and improved 3-D positioning accuracy.

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