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Three Dimensional Positioning Accuracy of KOMPSAT-1 Stereo Imagery

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Abstract : KOMPSAT-1 was launched on 21 December, 1999 and the main mission of the satellite is the cartography to provide the imagery from a remote earth view for the production of maps of Korean territory. For this purpose, the satellite has capability to tilt the spacecraft utmost ±45 degrees to acquire stereo satellite imagery in different paths.

This study aims to estimate the three dimensional positioning accuracy of stereo satellite imagery from EOC(electro-optical camera), a payload of KOMPSAT-1 satellite. For this purpose, the ground control points and check points were obtained by GPS surveying. The sensor modeling and the adjustment was performed by PCI software installed in KARI (Korea Aerospace Research Institute), which contained mathematical analysis module for KOMPSAT-1 EOC. The study areas were Taejon and Nonsan, placed in the middle part of Korea.

As a result of this study, we found that the RMSE (root mean square error) value of three dimensional positioning using KOMPSAT-1 stereo imagery can be less than 1 pixel (6.6 m) if we can use about 10 GCPs(ground control points). Then, a standard of FGDC (Federal Geographic Data Committee) of USA was applied to the result to estimate the three dimensional positioning accuracy of KOMPSAT-1 stereo imagery.

Key Words : KOMPSAT-1, Satellite Stereo Imagery, Three Dimensional Positioning.

1. Introduction

According to the advent of high resolution satellite imagery, the field of satellite imagery application has been expanded into the quantitative analysis from the conventional qualitative interpretation. The mapping technology using satellite stereo imagery has been rapidly developed, especially since SPOT-1 satellite launched in 1986 by France(Kruck, 1988). SPOT series have been successively launched and SPOT-4 was the latest one. Owing to the series of SPOT satellites, satellite stereo images have been achieved stably and continuously during last decade and now. Recently, mapping from satellite imagery has been ordinary business because numbers of commercial software for satellite image mapping have been developed and

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distributed (Al-Rousan et al., 1997). Considering that some satellite program to acquire high resolution satellite imagery are ongoing worldwide with the new millennium, currently, it is expected that satellite stereo image would replace the conventional aerial photographs in mapping project except large scale mapping (Zhou and Li, 2000). In GIS (Geographic Information System), three dimensional topographic analysis is often made up by reconstructing three dimensional topographic information using satellite stereo imagery. Not only in GIS but also in many fields of science and engineering, it is useful to collect three dimensional topographic information using satellite stereo images.

KOMPSAT-1 was launched on 21 December 1999 by KARI (Korea Aerospace Research Institute). The satellite has a sun-synchronous and near polar orbit of 685 km altitude. The orbit repetition is 28 days. The EOC (Electro Optical Camera), a payload of KOMPSAT-1 provides panchromatic satellite imagery with 6.6 m ground resolution and 17 km swath. Image of 800 km are taken in a path, which takes about 2 minutes to scan (Satellite Application Group, 1999). EOC has ability to tilt the spacecraft utmost 45 degrees which allows the satellite to take a pair of images of same ground area in different two paths to take stereo imagery (KOMPSAT Receiving and Processing Station, 1999). At least three days are required to take a pair of stereo image in Korean territory provided the weather condition permits. With this specification, the main mission of KOMPSAT-1 is the cartography to provide the imagery from a remote earth view for the production of maps of Korean territory. However, few stereo images are obtained until now because the satellite is in the early stage and it has been operated according to the first mission plan to collect entire image of Korean domestic territory. So, the accuracy of three dimensional topographic data generated from KOMPSAT-1 satellite stereo imagery has not been fully analyzed yet.

This paper estimated the three dimensional positioning accuracy of KOMPSAT-1 satellite stereo imagery, analyzing the geometrically processed results from stereo images of two areas, Taejon and Nosan, placed in the middle part of Korea. Data were processed using PCI software (PCI Geomatics, 1999) that had been installed at Data Receiving & Processing Laboratory in KARI. As a result of this study, the mapping extent of KOMPSAT-1 satellite stereo imagery was proposed.

2. Data and Experiments

Experiments were implemented according to the flow chart illustrated in Fig. 1. The flow chart of data processing was consist of three part; Data Input, Data Processing, and Analysis.

The input data was KOMPSAT-1 stereo images and the GCPs (Ground Control Points) of the sample areas. The size of KOMPSAT-1 image was 2592 x 2592 pixels and the file size of an image was about 7 Mbytes. The sample areas were selected in Taejon and Nonsan, placed in the middle part of Korea, where city, farming land, river, and mountain were well distributed. Generally, some ground survey points are required in three dimensional positioning using stereo images. GPS (Global Positioning System) surveying was implemented to measure the three dimensional coordinates of ground survey points that had been selected in stereo images to secure the identification of them in both images. Static

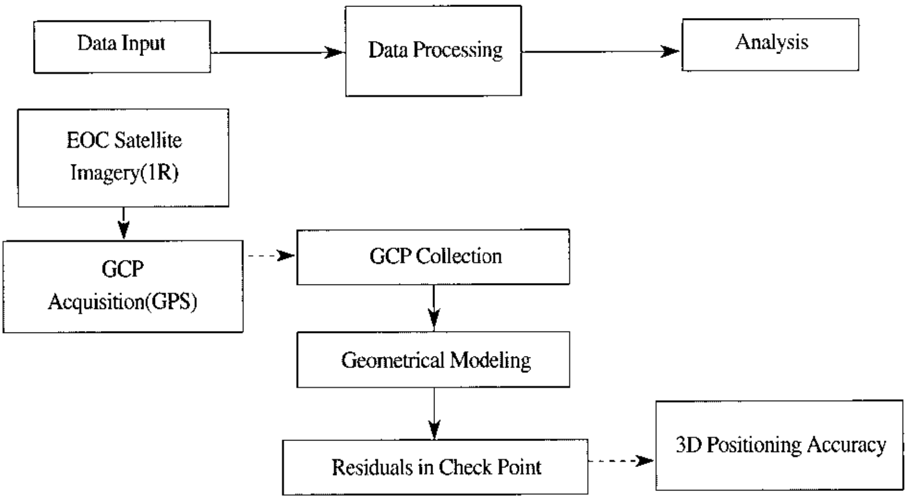


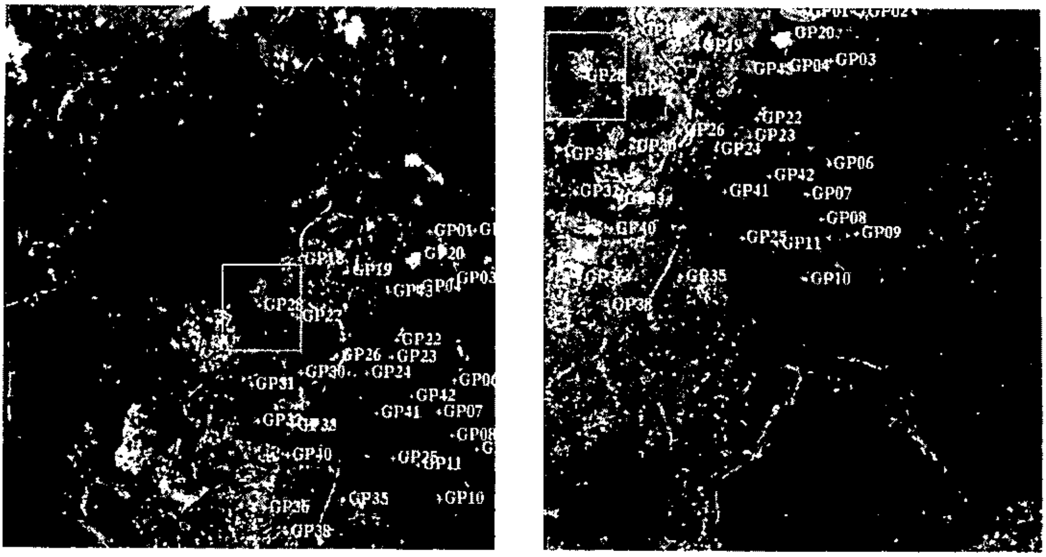
Fig. 1. Flow chart of the Experiment.

DGPS was applied in the GPS surveying and the base station was the permanent receiving station at the KAMC (Korea Army Mapping Corps) in Taejon. The receiving time was at least one hour in every ground survey point. Also, trilateral network adjustment was applied in the post processing stage to achieve high accurate coordinates. The reference ellipsoid in Korea is the Bessel 1841. In this paper, however, the WGS84 ellipsoid with which GPS satellites are operated was used as reference ellipsoid to avoid the errors due to the coordinate transformation between the Bessel 1841 and the WGS84. The WGS84 geographic coordinates are projected into the UTM (Universal Transverse Mercator) coordinates. Also, ellipsoidal heights were transformed into MSL (mean sea level) because MSL is used in common practice of mapping. In the height transformation, geoid model is required. However there was no official geoid model in Korea. So, we used CNU96 geoid model that had been developed by Chungnam University(Kang *et al.*, 1995).

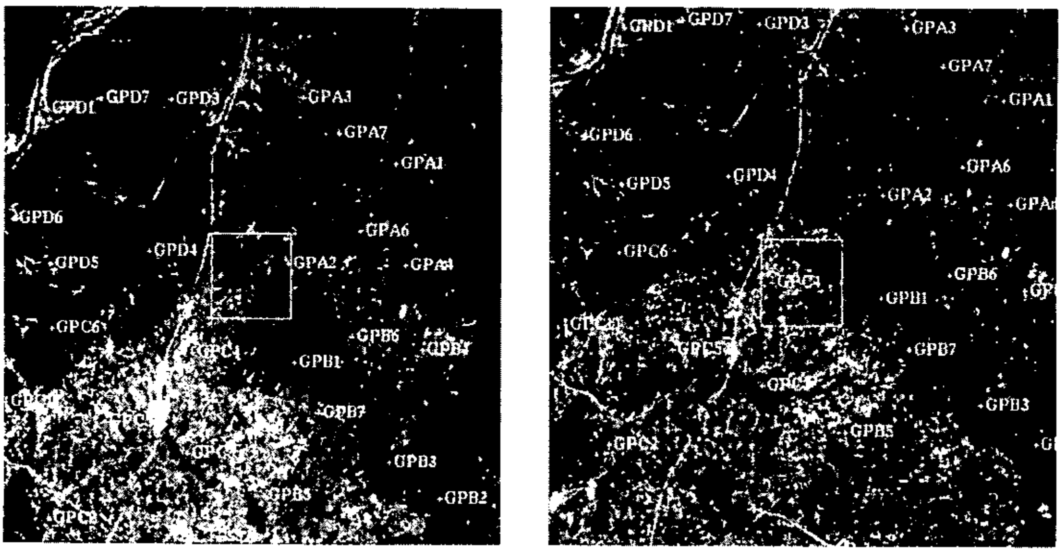
Total numbers of ground survey points were 31 in Taejon and 25 in Nonsan. The number would be plenty enough to be used in geometric modeling because the minimal number of GCP (ground control point) is four in PCI software to implement three dimensional geometric modeling of EOC imagery.

Fig. 2. illustrates the stereo images and arrangement of GCPs on images of both study areas. As seen in Fig 2., the portion of overlap area of Taejon is only about 1/4 of entire image placed at lower right corner on right image, but the images of Nonsan is fully overlapped. The height values were evenly distributed from 34.1m to 234.3 m in Taejon and from 9.3 m to 167.4 m in Nonsan. The vertical variations of GCPs would be enough to take account of vertical component in geometrical modeling.

The preprocessing level of each image was level 1R, which is one of the standard products of EOC imagery, and processed only in terms of the



(a) Taejon



(b) Nonsan

Fig. 2. Stereo images of study area and ground control points.

radiometric correction such as detector normalization and MTF correction.

The data processing in Fig. 1. was implemented using the OrthoEngine® SE(Satellite Edition) module of PCI software that had been installed in Data Receiving and Processing Laboratory of Satellite Operation and Application Center in KARI.

The OrthoEngine® SE module contains the mathematical model for KOMPSAT-1 EOC to analyze sensor geometry. The mathematical model was developed by Toutin at Canada Center for Remote Sensing (Toutin, 1995). The major advantage of the model is that the satellite modeling can be applied to almost all kind of satellite images including radar images. The mathematical model was first developed to process raw SPOT images. It has been modified to process other visible satellites, such as Landsat-TM, MOS-MESSR, KOMPSAT-1 EOC and SAR images. The modeling is based on the co-linearity condition, which represents the physical law of transformation between the image space and the ground space. The model reflects the physical reality of the complete viewing geometry and reflects all the distortions generated during the image formation as follows (PCI Geomatics, 1999):

1. Distortions due to the platform (position, velocity and orientation)
2. Distortions due to the sensor (orientation, integration time and field of view)
3. Distortion due to the Earth (geoid, ellipsoid and relief)
4. Distortion due to the cartographic projection (ellipsoid and cartographic)

As a result of this integration, the modeling equations are simple and straight forward, with few unknowns. The equations are the solved with few ground control coordinates.

After GCPs are collected in both stereo images, geometrical modeling are implemented. Then, the three dimensional coordinates and the residuals of check points can be computed. In the analysis step of Fig. 1., we can estimate the positioning accuracy of EOC stereo images from the residuals of check points.

3. Results and Discussions

The accuracy of three dimensional positioning using KOMPSAT-1 satellite stereo images was analyzed according to the variation of the number of GCPs. GCPs used in three dimensional positioning were varied from 5 points to 15 points as increasing the number by 2 points and three dimensional RMSE(root mean square error) of each case were analyzed using the residuals of check points which have invariant arrangement for each case. GCPs were selected to have even arrangement in each case with intention and the numbers of check points were 16 at Taejon and 10 at Nonsan. The results are shown in Table 1.

In Table 1, it was obvious that the positional accuracies of check points are enhanced as the number of GCPs are increased. Also, the accuracies of Taejon were somewhat lower than those of Nonsan in almost cases when same number of GCPs was used. Especially, 13 GCPs were required in Taejon to satisfy the RMSE less than 6.6 m, which is the ground distance of one pixel, but only 7 GCPs were required in Nonsan. It was supposed that the positioning accuracies were affected by the arrangement of GCPs. That is, the GCPs in Nonsan were evenly arranged in both entire images because almost all area was overlapped in stereo images, while those in Taejon were partly placed in both images because the stereo images were partly overlapped.

Considering the case of Nosan, it was able to be induced that the RMSE values of three dimensional positioning using KOMPSAT-1 satellite stereo imagery could be less than 6.6 m that corresponds to the ground distance of one pixel size in each three dimensional axes when about 10 GCPs evenly distributed in entire image are used.

Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy (NSSDA) published by FGDC (Federal Geographic Data Committee) of USA implements a statistical and testing methodology for

Table 1. RMSE of three dimensional positioning using KOMPSAT-1 satellite stereo imagery according to the variation of the number of GCPs.

Study area	No. of Check points	No. of GCP	RMSEx (m) (Δxmax)	RMSEz (m) (Δymax)	RMSEy (m) (Δzmax)
Taejon	16	5	4.386 (7.494)	2.988 (-5.677)	8.585 (-16.213)
		7	4.200 (-5.438)	3.513 (-6.415)	6.828 (-12.479)
		9	4.158 (-8.365)	2.500 (-4.561)	6.672 (-12.025)
		11	3.873 (-8.379)	2.449 (-4.302)	6.797 (12.605)
		13	4.162 (-8.751)	2.744 (-3.807)	6.305 (12.629)
		15	3.631 (-8.191)	2.620 (4.821)	6.037 (12.749)
Nonsan	10	5	4.322 (-9.683)	4.971 (9.612)	14.222 (25.256)
		7	3.594 (-7.161)	4.412 (5.797)	6.298 (-11.687)
		9	3.751 (-8.250)	3.104 (5.877)	3.964 (-7.717)
		11	3.927 (-8.909)	3.128 (5.396)	4.066 (-9.307)
		13	3.508 (-7.043)	2.845 (-5.019)	3.795 (-9.445)
		15	3.220 (-6.780)	3.086 (-6.66)	3.523 (-9.069)

estimating the positional accuracy of points on maps and digital geospatial data, with respect to georeferenced ground positions of higher accuracy (FGDC, 1998). According to the standard, horizontal accuracy at the 95% confidence level may be approximated by following formula

$$Accuracy_r = 2.4477 * 0.5 * (RMSE_x + RMSE_y) \quad (1)$$

Also, vertical accuracy at 95% confidence level is as follows:

$$Accuracy_z = 1.9600 * RMSE_z \quad (2)$$

According to the above formula, horizontal accuracy was able to be computed at 8.839 m and vertical accuracy at 7.769 m in the case of Nonsan when 9 GCPs were used. It shows that the positioning accuracy of KOMPSAT-1 stereo image could be less than 10 m in horizontal and vertical directions. Also, this means that the system requirements of KOMPSAT-1 to satisfy the mapping accuracy of 10 m(1) in both horizontal and vertical components were fully implemented.

4. Conclusions

In this paper, we tried to prove the feasibility of mapping using KOMPSAT-1 satellite stereo images through an experiment to estimate the three dimensional positioning accuracies. As a result of this study, it is shown that the RMSE of horizontal and vertical position from KOMPSAT-1 satellite stereo images could be less than 6.6 m that corresponds to the ground distance of one pixel if about 10 GCPs evenly distributed in entire image are used. Also, we found that map data having less than 10 m accuracy at 95 % confidence level can be produced using KOMPSAT-1 satellite stereo images. This satisfies the design value of KOMPSAT-1 in mapping accuracy.

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