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Photogrammetric Modeling of KOMPSAT Stereo Strips Using Minimum Control

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Abstract

This paper describes an experiment for three-dimensional positioning for a pair of KOMPSAT stereostrips using the ancillary data and a single ground control point.

The photogrammetric model for three-dimensional positioning was performed as follows: first, initialization of orbital and attitude parameters derived from ancillary data; second, adjustment of orbital and attitude parameters for the satellite to minimize the ground position error with respect to a GCP using the *collinearity condition*; third, determination of actual satellite position; and lastly, space intersection.

This model was tested for a pair of stereo strips with 0.6 base-to-height ratio and GCPs identified from a 1:5,000 scale digital map. As the result, the satellite position offset was corrected by only one GCP and the accuracy for the geometric modeling showed 38.89m RMSE.

Keywords : *KOMPSAT, Ancillary Data, 3-D Positioning Modeling, Stereostrip*

1. Introduction

KOMPSAT (KOrea Multi-Purpose SATellite) was launched by KARI(Korean Aerospace Research Institute) for 1:25,000 scale mapping and planning of the land use on 21 December 1999 (KARI, 2002). KOMPSAT produces the panchromatic images of 6.6 m ground sample distance with the swath width of 17 Km at nadir. Even though KOMPSAT satellite does not have as high resolution as IKONOS, it provides the ancillary data of the satellite to the users and still opens the possibility for geometric modeling with minimum GCPs (Ground Control Points).

To acquire 3-D position from the satellite stereo images, the geometric modeling which establishes the relationship between object points and their corresponding image points needs to be carried out (Hopkins, 1991).

The GCPs play an important role for the precise geometric modeling. Even when satellite images are available, we often encounter the troubles due to the accessibility, time, and costs to acquire the GCPs. In particular, it is a serious problem when we need to perform 3-D positioning or topographic mapping for inaccessible area. For these reasons, the geometric modeling using the ancillary data contained in the satellite images with minimum GCPs or without GCPs can give much advantage (Yoo et al. 2001, Chien et al. 1998).

The purpose of this paper is the precise geometric modeling of sensor via satellite orbit simulation. To accomplish this end 3-D positioning method using the ancillary data was developed for analyzing the single stereo images and strip stereo images of KOMPSAT. We improved the accuracy of sensor modeling with minimum GCPs through the orbit error correction.

2. Ancillary Data of KOMPSAT Satellite Image

The ancillary data are provided with HDF (Hierarchical Data Format). The provided size of a single scene is 2,592 pixels and 2,797 lines. The ancillary data provides general parameters, general imaging

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Table 1. Ancillary Data of KOMPSAT

Parameters	Description
General Parameters	Satellite Name, Scene ID, Processing Level, No. of Pixels Per Line, No. of Pixels Lines Per Image, Scene Quality, etc.
General Imaging Data	Image Orientation Angle, Angle of Incidence, Satellite Altitude, etc.
Parameters for Sensor Modeling	Satellite Position and Velocity Data, Scene Center Time, Sensor to Body Transformation Data, Body to Flight Transformation data, Flight to ECEF Transformation data, Sensor Look Vectors of End Detectors, Detector Gain and Bias Data.
Orbital Elements	IFOV, FOV, Viewing Angle, Radial Speed, Eccentricity, Height of Satellite, Inclination, Angular Speed, Argument of Perigee, Earth Satellite Distance, Nominal Pitch, Satellite Argument.

data, parameters for sensor modeling, and orbital elements (Table 1).

3. Geometric Modeling of KOMPSAT Stereo-strip Images

KARI, operating KOMPSAT-1 satellite now, provides only a single pair of stereo images to the general users. We created a strip images by manually connecting 6 pairs of stereo images along the two paths.

Ephemeris data with strip imagery is treated just like a single image frame provided that the time at strip center with respect to 1950 epoch.

While the KOMPSAT satellite scans the earth, a continuous imagery is produced, which is then subdivided by KARI into individual image frames of N_s scan lines each.

A strip of KOMPSAT imagery is different from a strip of aerial photographs in the sense that KOMPSAT strip does not have areas of overlap between successive image frames along the strip. However, due to the way image frames are produced from the strip, there are some few hundred repeated scan lines between successive image frames which causes artificial areas of overlap. A continuous strip is treated by the developed mathematical model as one image frame with the number of scan lines equals the total number of scan lines in the strip. Important quantities that must be calculated in order to use a strip of KOMPSAT imagery are the time at each frame center relative to strip center, δt_f. If ephemeris data are to used, then the time at strip center relative to 1950 epoch, t'_f, will also be needed(Makki, 1991).

A strip of an odd number of frames is relatively easier to process than a strip of even number of frames. In a strip of odd number of frames, the strip center coincides with the center of the central frame. If we let I_c denotes the serial number of the central image frame, then for any frame i in the strip we can calculate its δt_f from:

$$\delta t_{f_i} = t'_{f_i} - t'_{f_t} \qquad (1)$$

For a strip of an even number of frames, we need to calculate first the amount of overlap between each two successive frames in terms of time. This amount of overlap for any frame i is denoted by δt_i, and is calculated from:

$$\delta t_i = \Delta t_c N_s - [(t')_{i+1} - (t')_i]$$
$$i = 1, \ldots, \ldots, N_f - 1 \qquad (2)$$

where Δt_c is the time for imaging one scan line, N_s is the number of scan lines per frame, and N_f is the number of frames in the strip. From equation (2) it is clear that the last frame in the strip does not have a δt value. A strip of even number of frames has its center at the middle of the area of overlap between the two central frames. If we let I_{c1} and I_{c2} denote these two central frames, then it can be shown that $I_{c1} = N_f/2$, and that $I_{c2} = I_{c1} + I$, therefore, δt_f of any frame I_f can be calculated from :

$$\delta t_f = \Delta t_c N_s (I_{c1} - I_f + 1/2) \delta t_i - 1/2 \delta t_{I_{c1}}$$
$$I_f \leq I_{c1} \qquad (3)$$

$$\delta t_f = \Delta t_c N_s (I_f - I_{c2} + 1/2) \delta t_i - 1/2 \delta t_{I_{c1}}$$
$$I_f \rangle \; I_{c1} \qquad (4)$$

The time at strip center relative to 1950 epoch, t'_s, for a strip of odd number of frames is equal to t'_f of the central image frame. however, for a strip of even number of frame. t'_s is found by calculating the sum of t'_f and δt_f of any frame in the strip.

Fig. 1 shows the calculation of the frame center times after removing the overlapped area of images ($\delta t_1 \sim$

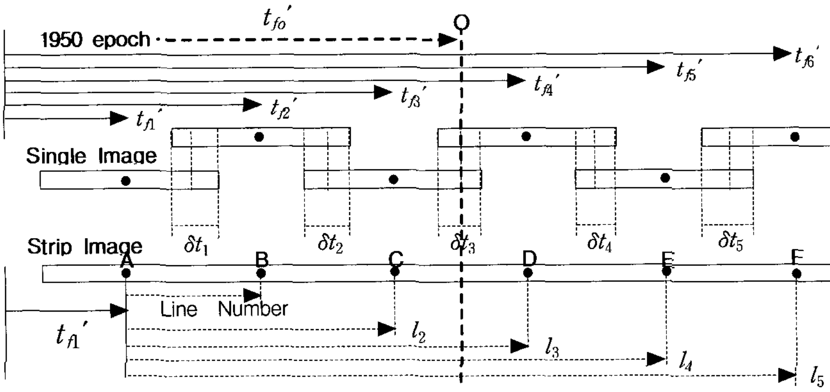


Fig. 1. Configuration of strip image.

δt_6) and connecting images continuously. Since each single image provides the frame center time from 1950 epoch ($t_{f1}' \sim t_{f6}'$), we can calculate the frame center time (t_{f0}') of the strip image from 1950 epoch using $t_{f1}' \sim t_{f6}'$

$$1950 epoch \sim D = t_{f4}' = t_{f1} + l_3 \times \Delta t_c \tag{5}$$

where, Δt_c is the time to scan one line.

Using the result of the time difference from frame center, the orbit parameters and sensor attitudes for some points (row, col) in the strip stereo image, actual satellite position vector ($\vec{P}_{act}$) is determined by the sum of nominal position vector ($\vec{P}_{nor}$) and satellite position offset vector ($\triangle_s$). The result is shown in Equation 1.

$$\vec{P}_{act} = \vec{P}_{nor} + \triangle_s \tag{6}$$

where, the nominal position vector ($\vec{P}_{nor}$) is computed from the rotation matrix and the radius of satellite orbit (ρ_s). It is affected by several forces such as temperature variation, irregularity of earth gravity, gravitations of moon and sun, and the others (Chobotov, 1996).

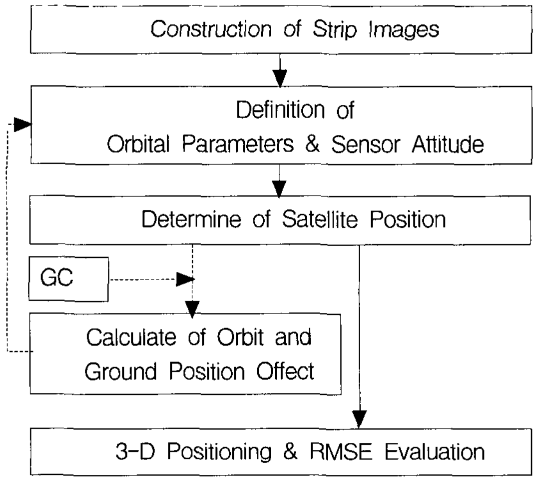


Fig. 2. Geometric Modeling of Stereostrip Images.

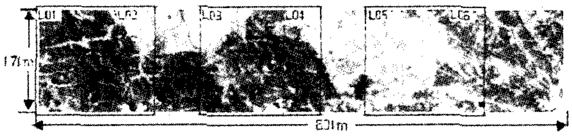
The 3-D position vectors of the object points in ECEF coordinate system ($\vec{X}$) are computed from actual satellite position vector ($\vec{P}_{act}$), the image coordinates of the points ($\vec{x}$) in sensor coordinate system, scale factor(s), and the ground position deviation ($\triangle_g$) (Makki, 1991).

$$\vec{X} = \vec{P}_{act} + sR\vec{x} + \triangle_g \tag{7}$$

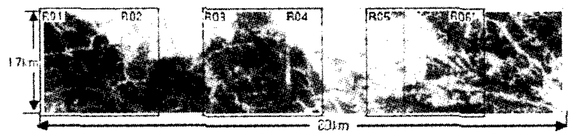
4. Test Results Analysis

4.1 Test Data Set

The left and right strip stereo images were composed of 6 continuous single stereo images acquired from two different orbit tracks with look angles of -12°, +19° and 0.6 base-to-height ratio (B/H). The two strip images were sampled on 28 April and 1 May 2000, and the image sizes are 2,592×12,816 pixels (17 km × 80 km)



(a) Left Strip Image



(b) Right Strip Image

Fig. 3. Stereostrip Images of KOMPSAT.

(Fig. 3). The ground coordinates for GCPs were manually digitized from 1:5,000 scale digital maps. Among the 158 test points, one or two points are used as GCPs and remaining points are used as check points.

4.2 Modeling Results Analysis

The experiment includes the testing of the proposed scheme for 3-D positioning from a pair of KOMPSAT strips. For evaluating the accuracy of 3-D geometric modeling, the major test was focused on the comparative analysis of each 6 single stereo images and strip stereo images. First, we calculated the orbit parameters, the sensor attitudes (κ, ϕ, ω), and the nominal satellite position using the ancillary data only. The absolute position offset on the ground was about 14.9 km, but the relative positional error was 11.6 m.

Orbital parameters for each ephemeris point were calculated using ephemeris data that comes with EOC image header file. The rate of changes for orbital parameters is very small, when they are estimated for ephemeris points. For left strip image, t_f is 596.045185 second, i is in 98.173625 degree, Ω is in 137.330821 degree, and a_s is in 7065.661485 km. However, argument of perigee (ω;114.141443 degree) showed a slight bigger rate of change compared to that of other orbital parameters. Table 3 summarizes the estimated mean values of orbital parameters for left and right strip.

When orbital parameters are calculated for ephemeris points, polynomial enables to compute orbital parameters in any given time since the rate of changes are small. Third order polynomials describe the orbital parameter in a specific time relative to the image frame center line. To estimate three dimensional rotation angles of sensor, the attitude information inside the ancillary data was used. For SPOT imagery, look angle is provided in the ancillary information. KOMPSAT, however, look angle can only be derived by using attitude data and Table 4 shows the calculated sensor attitude.

In a process for 3-D positioning, we could find that there is the constant offset of satellite position along the satellite orbit track. We assumed that the constant offset was caused by inconsistency between the time of image frame center and the time of ephemeris points provided by ancillary data. The time difference between image frame center and ephemeris points was corrected by using one GCP and then other orbit parameters were updated accordingly (Table 5).

In this case, we adjusted the frame center time of each image to 2.2463 second for left strip image and 2.0789 second for right strip image respectively. We could correct the satellite position offset occurred along progressive direction of satellite track.

Performing 3-D positioning of each 6 single stereo images using one GCP, the average accuracy was 14.41

Table 2. 3-D Positioning Errors of Stereostrip Images Using only Ancillary Data

Stereostrip	Check Points	Absolute Position Errors (RMSE)				Relative Position Errors(m)
		ΔX (km)	ΔY (km)	ΔZ (km)	ΔP (km)	
	158	8.7	3.9	11.5	14.9	11.6

Table 3. Orbital Parameters of Strip Images

Strip	t_f (sec.)	i (deg.)	Ω (deg.)	ω (deg.)	a_s (km)	e_s
Left	596.045185	98.173625	137.330821	114.141443	7065.661485	0.001427
Right	585.929351	98.173625	132.865017	109.249873	7066.385173	0.001399

Table 4. Attitude of Strip Images

Strip	roll (deg.)	pitch (deg.)	yaw (deg.)
Left	-12.244337	-0.026929	0.004583
Right	19.123612	-0.287911	0.094366

Table 5. Correction of Orbital and Attitude Parameters using one GCP

Strip	Correction of Δt_f (sec.)	Correction of Attitude (rad)		
		$\Delta\omega$	$\Delta\phi$	$\Delta\kappa$
Left	2.2463	-0.001419	0.000082	0.000000
Right	2.0789	-0.002075	0.000122	0.000001

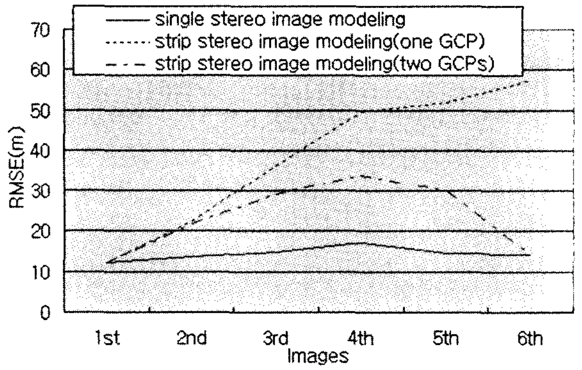


Fig. 4. RMSE of 3-D modeling for single and strip stereo images.

m RMSE (Fig. 4). To compare the accuracy of these individual stereo images with the strip stereo images consisted of these images, we located one GCP at the first image pair of the strip stereo images. As the result of the successive error correction to next images (Fig. 4), the accuracy was 38.89 m RMSE. In addition, the further distance from the first image to the 6th images, the larger 3-D positioning error become to 57.6 m RMSE.

To remove this kind of error, we implemented the error correction after locating one GCP on the first and the 6th image respectively and then confirmed that the 3-D positioning error was reduced to about 1.5 times than the case for only one GCP on the first image.

5. Conclusions

Using the stereo and the strip images with the ancillary data sets of KOMPSAT, geometric modeling for three dimensional positioning was performed and its accuracy was evaluated accordingly.

In the geometric modeling procedures, the ephemeris data included in the ancillary data were used to calculate orbital parameters, sensor attitudes, and satellite position. We found that there existed inconsistency between the time of ephemeris data and the time of image frame center, which caused the significant offset of the satellite position. We successfully adjusted this time inconsistency through the geometric adjustment procedures. The actual three dimensional satellite positions of the stereo and the strip images were modeled by using only one or two GCPs. For the image strips consisted of 6 image frames, we could obtain accuracy of about 38.39 m RMSE using only one GCP and ancillary data, and about 25.5 m RMSE using stereostrip image pairs with two GPCs.

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