

# MODELING OF ABSOLUTE ORIENTATION OF ADJACENT SATELLITE IMAGE STRIPS USING A FEW GROUND CONTROL POINTS

Dongwook Kim, Taejung Kim

Dept. of Geoinformatic Eng., Inha University, Republic of Korea  
Barkim@inhaian.net, tezid@inha.ac.kr

Commission I, Working Group I/5

**KEY WORDS:** Orbit-modeling, Strip, SPOT-3, GCP, DEM, Sensor model, Orbit-attitude model

## ABSTRACT:

This paper presents accuracy and stability of orbit modeling. Orbit modeling is carried out using the stereo strips which were taken by SPOT-3 satellite, a large number of GCPs (Ground control points) and orbit-attitude sensor model as a rigorous sensor model. To verify the accuracy and stability of orbit modeling, we analyzed orbit model error against whole strip and absolute orientation accuracy of orbit-attitude models established separately. Furthermore, For Additional verification of orbit model, we generated DEMs (Digital Elevation Level) using results of orbit modeling. On all of the tests, we obtained three-dimensional object-space coordinates have high accuracy and stability against whole strip. In this study, we used orbit modeling proposed by Kim(2005) focused on the strip images which have a same orbital characterization. That's useful for inaccessible area analyzing. In the future, if we apply that orbit modeling for the inaccessible area, we will able to acquired three-dimensional object-space coordinates about 420km in distance. This reseach results will help people to analyze inaccessible area without direct contact of the area.

## 1. INTRODUCTION

Sensor modeling is the most important process in order to acquire three-dimensionanl object-space coordinates information from satellite images. In order to carry out sensor modeling, we need a number of GCPs (Ground Control Points). The accuracy of GCPs determines the accuracy of sensor models and hence the accuracy of the 3D information. Hence one usually use GCPs derived from GPS measurements or extracted from large scale maps. However, this requirement of accurate GCPs has a weak point. For example, field measurement has a restriction when the region of interest is not accessible. The GCP requirements increase time and cost for satellite image processing.

To improve this situation, many studies dealt with sensor modeling without using GCPs or using smaller number of GCPs. For example a technique for modeling image strips with small number of GCPs and tie points was proposed using the Rational Function Model (RFM) (Grodecki, J. and Dial, G., 2003). Other approaches proposed include the modeling of a whole image strips, instead of individual images, using rigorous sensor models based on satellite orbit and attitude parameters (Kim, 2005; Kim, 2006, Kim et al., 2007). In this approach, orientation parameters for the whole orbit were firstly extracted from satellite metadata and errors within the parameters were adjusted using a few control points. It was reported that if angular biases are used for adjustment, it is possible to establish accurate sensor models for the whole strip with a few GCPs regardless of the location of GCPs (Kim et al., 2007)

This paper extends the previous studies regarding orbit modeling with rigorous sensor models. Here we focus the possibility of establishing absolute orientation between two stereo strips. Model parameters for each single strip will be estimated using techniques previously proposed. Then we will check whether such model parameters can be used for absolute

orientation between two stereo strips and for generation of 3D information.

## 2. ORBIT ATTITUDE MODEL

In this paper, we used orbit-attitude model (Kim., 2006) as a rigorous sensor model for modeling image strips. Orbit-attitude model is also based on the collinearity equations. It uses as orientation parameters satellite attitude angles, which are expressed by **Roll, Pitch, Yaw**, and orbital parameters, which are expressed by satellite position vector **P** and velocity vector **V** (Kim, 2006). Orbit-attitude model has the following matrix form.

$$\begin{pmatrix} x \\ y \\ -f \end{pmatrix} = \lambda \mathbf{R}_{rpy}^T \mathbf{R}_{p,v} \begin{pmatrix} X - X_s \\ Y - Y_s \\ Z - Z_s \end{pmatrix} \quad (1)$$

Where  $f$  = focal length

$x, y$  = image coordinates

$\lambda$  = ratio constant

$X, Y, Z$  = ground coordinates

$X_s, Y_s, Z_s$  = position of satellite

$\mathbf{R}_{rpy}$  = rotation matrix which is expressed satellite attitude angle

$\mathbf{R}_{p,v}$  = rotation matrix which is expressed satellite position vector and velocity vector

Orbit-attitude model is one of the rigorous model explaining the relationship between image coordinates and ground coordinates using physical parameters of the sensor and platform. It can be used to model a single scene. In previous research, it worked as good as other rigorous models for single scene modeling (Kim and Dowman, 2005). It was also found that this model has advantages over other rigorous models in modeling entire image strips with a few GCPs located on the top or bottom of the strip (Kim and Dowman, 2005). This model will be further tested here for absolute orientation and 3D information generation from stereo image strips.

### 3. TEST DATA

#### Test Image

Tested strip images taken by SPOT-3 satellite in a row. Distance of whole strip is 420km. One SPOT-3 scene includes a region of 60km by 60km. The whole strip is made of seven scenes. Table 1 summarised the details of image strip used for test.

| ID                | Left strip          | Right strip       |
|-------------------|---------------------|-------------------|
| <b>Tilt Angle</b> | +19.8               | -23.4             |
| ID                | Date of Acquisition |                   |
| <b>Choonchun</b>  | 02:39:16/04/04/95   | 02:07:50/01/28/95 |
| <b>Yangpyung</b>  | 02:39:25/04/04/95   | 02:07:58/01/28/95 |
| <b>Cheonahn</b>   | 02:39:33/04/04/95   | 02:08:07/01/28/95 |
| <b>Daejeon</b>    | 02:39:42/04/04/95   | 02:08:15/01/28/95 |
| <b>Jeonju</b>     | 02:39:50/04/04/95   | 02:08:24/01/28/95 |
| <b>Kwangju</b>    | 02:39:59/04/04/95   | 02:08:32/01/28/95 |
| <b>Nhaju</b>      | 02:40:07/04/04/95   | 02:08:40/01/28/95 |

Table.1 characterization of SPOT-3 Image

#### Test GCPs

GCPs used in experiments were acquired from differential GPS survey. Left strip image had 152 GCPs and Right strip had 149 GCPs. The GCPs were acquired from GPS survey. Fig. 1 shows the images and configuration of GCPs within a images for the let strip.

### 4. EXPERIMENT RESULTS

Firstly, model parameters for the whole left image strip and whole right image strip were estimated separately using the orbit-attitude model. Within each strip, only GCPs from the top scene, Choonchun, was used for modeling and biases in attitude angles were estimated during adjustments. After estimating orbit-attitude model parameters using model GCPs, other GCPs were used to check the accuracy of the orbit models.

Table 2 and 3 show orbit modeling results. GCPs with smaller ID are from Choonchun scene, which were used for modeling. GCPs with larger ID are from the bottom scene, Nhaju scene. The tables also show root mean square errors for all model and check GCPs. Entire model error shows that within 2 pixel error (1pixel : 10m) against whole GCP points. Accuracy of orbit model shows high stability about left and right strip images. This results verified that orbit modeling was achieved for the whole strips.

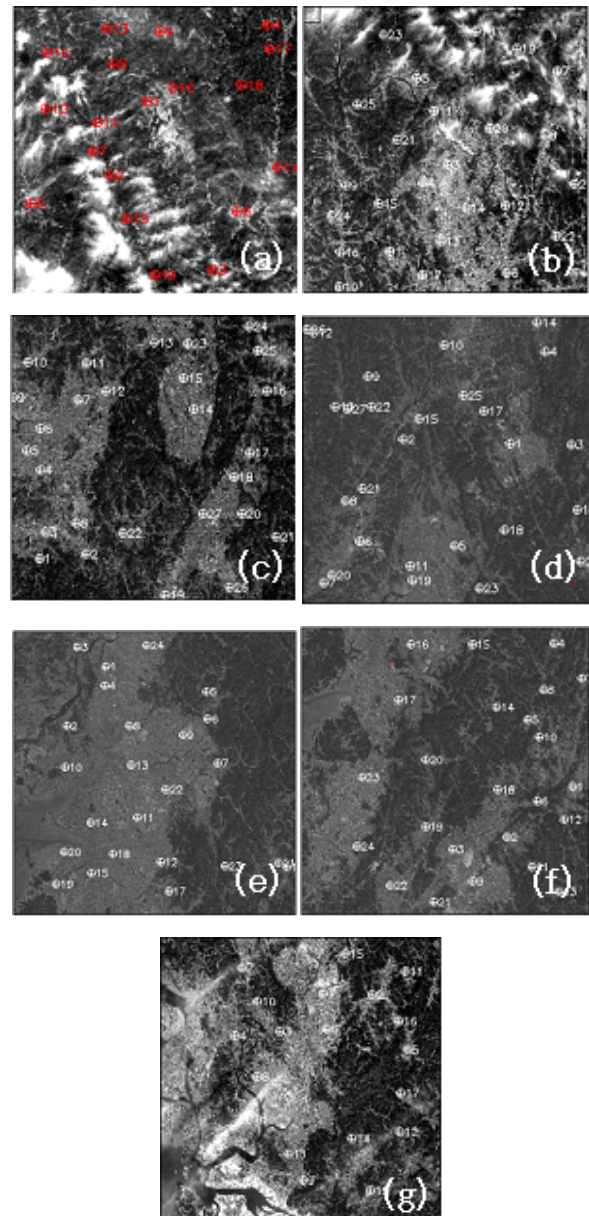


Fig 1. Configuration of GCPs, (a) Choonchun, (b) Yangpyoung, (c) Cheonahn, (d) Daejeon, (e) Jeonju, (f) Kwangju, (g) Nhaju

| GCP ID      | Pixel Error |         |           |
|-------------|-------------|---------|-----------|
|             | Column      | row     | Magnitude |
| 1           | 0.3052      | 1.0675  | 1.1102    |
| 2           | -0.5868     | -0.9914 | 1.1520    |
| 3           | 1.1251      | -0.3542 | 1.1795    |
| 4           | 1.8606      | -0.1296 | 1.8651    |
| 5           | -0.9536     | 0.6140  | 1.1342    |
| .           |             |         |           |
| .           |             |         |           |
| .           |             |         |           |
| 148         | -0.2912     | 0.0035  | 0.2912    |
| 149         | 0.3644      | -0.4626 | 0.5889    |
| 150         | 1.1981      | 1.1431  | 1.6559    |
| 151         | 0.5544      | -0.8487 | 1.0137    |
| 152         | 0.0664      | 0.6242  | 0.6278    |
| <b>RMSE</b> | 1.1456      | 1.0722  | 1.5691    |

Table 2. Left strip RMSE Error

| GCP ID | Pixel Error |         |           |
|--------|-------------|---------|-----------|
|        | Column      | row     | Magnitude |
| 1      | -0.1633     | 0.8079  | 0.8242    |
| 2      | 0.37999     | -1.5742 | 1.6194    |
| 3      | -1.7325     | -1.3087 | 2.1712    |
| 4      | 0.8105      | -0.1391 | 0.8224    |
| 5      | 1.0212      | -0.0405 | 1.0221    |
| .      |             |         |           |
| .      |             |         |           |
| .      |             |         |           |
| 145    | 1.0610      | 1.4272  | 1.7784    |
| 146    | 0.9773      | 0.2052  | 0.9986    |
| 147    | -0.3475     | 0.0753  | 0.3556    |
| 148    | -0.0838     | -0.1775 | 0.1963    |
| 149    | 0.7588      | 2.1619  | 2.2912    |
| RMSE   | 1.0505      | 1.1769  | 1.5775    |

Table 3. Right strip RMSE Error

**Analysis of Absolute Orientation Error**

In this experiment, we analysed absolute orientation accuracy of orbit-attitude models established separately. Among GCPs used, 149 GCPs were observed in the left and right images. Therefore these points were used as tie points and ground coordinates for each tie points were calculated using the orbit-attitude models established. These coordinates were compared with actual ground coordinates of GCPs and accuracy was compared. Table.3 shows the error of absolute orientation against whole strip. Results of absolute orientation show that errors for all scenes were within 20m. Note that Choonchun scene was the scene used for modeling and Nhaju the scene 420km apart from the Choonchun scene. The magnitude of errors was similar for all scenes. This means that using GCPs measured from one stereo pair, it was possible to establish absolute orientation for orbital strip of 420km.

| Scene Area | Horizontal Error(m) | Vertical Error(m) |
|------------|---------------------|-------------------|
| Choonchun  | 14.29               | 11.51             |
| Yangpyung  | 14.86               | 11.41             |
| Cheonahn   | 9.61                | 14.37             |
| Daejeon    | 11.07               | 14.19             |
| Jeonju     | 13.29               | 10.10             |
| Kwangju    | 11.70               | 12.82             |
| Nhaju      | 11.14               | 13.32             |

Table 3. Absolute Orientation Error

**Analysis of DEMs**

For Additional verification of orbit model, we generated DEMs using results of orbit modeling. We also generated DEMs separately after establishing sensor models for the scene using GCPs extracted for the scene. We compared the DEMs generated using orbit modeling and the DEMs generated using scene modeling. orbit modeling and another DEM which is generated from GCPs. Through this, we aimed to check whether orbit modeling can be used for generation of 3D information extraction. For DEM generation, we used a DEM generation S/W developed in-house.

As before, orbit models for the whole strip were established from GCPs of the Choonchun scene. Then, DEMs were generated for two scenes: Daejeon scene, which was 240km apart from the Choonchun scene and Nhaju scene, which was 420km apart.

For Daejeon and Nhaju stereo pairs, sensor models for each scene were established separately using GCPs for each scene. Then a DEM for each pair was generated.

Fig. 2 and 3 show DEM of each region from each model. All DEMs produced were compared with DTED level 2 dataset. The results of comparison were shown in table 4. The results of Daejeon scene presents that DEM from orbit modeling has the same level of accuracy as the DEM from scene modeling. DEM of Nhaju has a similar result like the Daejeon case, but accuracy of Nhaju DEM has low accuracy than Dae-jeon DEM (mainly due to clouds within the scene).

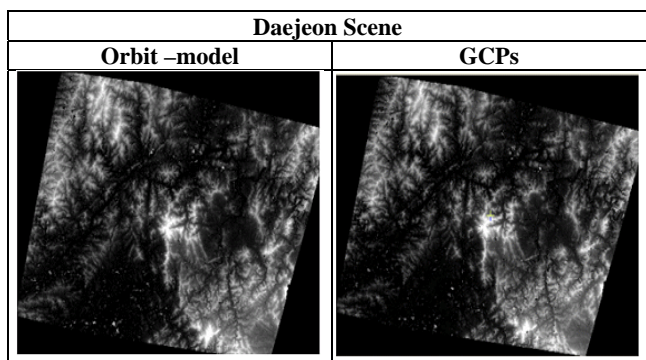


Fig.2 DEM of Daejeon image

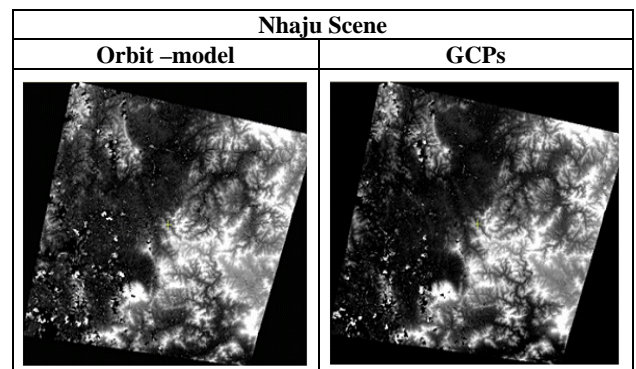


Fig.3 DEM of Nhaju image

| Scene area | RMSE(m)    |      |
|------------|------------|------|
|            | Orbit-base | GCPs |
| Dae-jeon   | 32         | 32   |
| Nha-ju     | 49         | 44   |

Table.4 Results of DEM

Analysis of DEM accuracy seems to support that orbit modelling techniques can be used for generation of 3D information. With GCPs extracted from one scene, it was possible to generate DEMs for whole image strip of 420km with little accuracy degradation.

## 5. CONCLUSION

This paper presents experiments carried out to test the ability of orbit modeling techniques for absolute orientation and 3D information extraction. Results of orbit modeling and results of absolute orientation show satisfactory. Orbit model error shows very high accuracy (within 2pixel) and absolute orientation error shows horizontal error and vertical error which has a high accuracy and stability against whole strip. Additional DEM generation experiments also support the accuracy of orbit modeling. We were able to acquire three-dimensional object-space coordinates about 420km in distance

The results imply that this orbit modeling technique can be used for 3D information over inaccessible area. The results also imply that a smaller number of GCPs may be acceptable when processing satellite image strips. This paper has a value in that it will be able to acquire terrain position information without direct contact of the area of interest and it may contribute to the approach of sensor modeling without using GCPs.

## ACKNOWLEDGEMENTS

This research was supported by the Agency for Defense Development, Korea, through the Image Information Research Center at the Korea Advanced Institute of Science & Technology.

## REFERENCE

- Gupta, R. and Hartley, R., 1997. Linear Pushbroom Cameras, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 19(9), pp. 963-975.
- Jacek, G. and Gene, D., 2003. Block Adjustment of High-Resolution Satellite Images Described by Rational Polynomials, *Photogrammetric Engineering & Remote Sensing*, 69(1), pp. 59-68.
- Kim, T. 2006. Modeling Satellite Orbital Segments using Orbit-Attitude Models, *Korean Journal of Remote Sensing*, 22(1), pp. 63-73.
- Kim, T. 2005. Investigation on the Accuracy of bundle Adjustments and Exterior Orientation Parameter Estimation of Linear Pushbroom Sensor Models, *Korean Society of Surveying, Geodesy, Photogrammetry, and Cartography*, 23(2), pp. 137-145.
- Kim, H. and Kim, T., 2006. Accuracy analysis of SPOT Orbit Modeling Using Orbit-Attitude Model, *The Korean for Geo Spatial Information System*, 14(4), pp. 27-36.
- Kim, T. and Dowman, I.J., 2006. Comparison of Two Physical Sensor Models for Satellite Images. *The Photogrammetric Record*, 21(114), pp. 110-123.
- Kim, T. Kim, H., and Rhee, S., 2007. Investigation of physical sensor models for modeling SPOT3 orbits. *The Photogrammetric Record*, 22(119), pp. 257-273
- Kim, T. Kim, S. and Shin, D., 2000. Camera Modeling of Linear Pushbroom Images-Quality analysis of various algorithms, *Korean Journal of Remote Sensing*, 16(1), pp. 73-86.
- Orun, A. B. and Natarajan, K., 1994. A modified bundle adjustment software for SPOT imagery and Photography : Tradeoff, *Photogrammetric Engineering & Remote Sensing*, 60(12), pp. 1431-1437.
- SPOT Image, 1997. *The SPOT Scene Standard Digital Product Format*, S4-ST-73-01-SI.
- SPOT Image, 2002. *SPOT Satellite Geometry Handbook*, S-NT-73-12-SI.