MODELING SATELLITE IMAGE STRIPS WITH COLLINEARITY-BASED AND ORBIT-BASED SENSOR MODELS

Hyunsuk Kim, Taejung Kim

Dept. of Geoinformatic Engineering, Inha University
sie06@inhaian.net, tezid@inha.ac.kr

ABSTRACT: Usually to achieve precise geolocation of satellite images, we need to get GCPs (Ground control points) from individual scenes. This requirement greatly increases the cost and processing time for satellite mapping. In this article, we focus on finding appropriate sensor models for entire image strips composing of several adjacent scenes. We tested the feasibility of modelling whole satellite image strips by establishing sensor models of one scene with GCPs and by applying the models to neighboring scenes without GCPs. For this, we developed two types of sensor models: collinearity-based type and orbit-based type and tested them using different sets of unknowns. Results indicated that although the performance of two types was very similar, for modelling individual scenes, it was not for modelling the whole strips. Moreover, the performance of sensor models was remarkably sensitive to different sets of unknowns. It was found that the orbit-based model using attitude biases as unknowns can be used to model SPOT image strips of 420 Km in length.

KEY WORDS: geolocation, sensor models, collinearity-based sensor models, orbit-based sensor models, satellite image strips

1. INTRDUCTION

Sensor models provide the geometric relationship between the image coordinates and the ground coordinates. There are many kinds of sensor models and these models can be categorized as physical and generalized models. Physical models are established by using physical parameters of sensors and platforms such as focal length, the dimensions of charge-coupled devices(CCDs), attitude and position of satellites. The representative physical models are the modified collinearity equations proposed for linear pushbroom of satellite(Gugan and Dowman, 1988; Orun and Natarajan, 1944), and orbit-attitude models based on ephemeris data of satellite(Wollff, 1985; Radhadevi et al.1998; SPOT image, 2002). Generalized models use more independent parameters to sensors and platforms. Gupta and Hartley(1977) proposed DLT(Direct Linear Transforms) and Tao(2001) proposed RFM(Rational Fuction Model). This paper has a focus on testing collinearity-based sensor models and orbit-based sensor models using satellite image strips. Image strips compose of a few scenes of the same orbital segments.

Usually, sensor models require a set of ground control points with a respect to individual scenes. Precise geolocation has an important effect on the accuracy of the models. Preparing ground control points takes the cost and processing time. This paper, we present research for acquiring accurate geolocation of unknown regions without ground control points. This research used SPOT-3 image strips within 420 Km, while one scene coverers an area about 60x60 Km^2, and ground control points acquired from GPS survey.

SPOT takes images by linear pushbroom cameras and one panchromatic SPOT scene includes 6000 image lines. For each line of images, Exterior orientation parameters of position, velocity and attitude of satellite must be interpolated. The interpolation method of position and velocity of satellite was chosen as Lagrange polynomial. And the attitude interpolation as piecewise-linear. For modelling satellite image strips, we set up collinearity-based and orbit-based sensor models with GCPs of a scene and then we analyze the possibility of modelling other scene by using the sensor model of one scene.

2. COLLINEARITY-BASED MODELS

Collinerity equation is widely used for a sensor model of aerial photo and Gugan and Dowman(1988) presented the modified equation for liner pushbroom sensors. In SPOT satellites, if the moving direction of sensor is along the x-axis, CCDs arrays are directed to the y-axis, collinearity-based models are shown as bellow

$$x = 0 = -f\frac{r_{11}(X - X_S) + r_{21}(Y - Y_S) + r_{31}(Z - Z_S)}{r_{13}(X - X_S) + r_{23}(Y - Y_S) + r_{33}(Z - Z_S)} \qquad (1)$$

$$y = -f\frac{r_{12}(X - X_S) + r_{22}(Y - Y_S) + r_{32}(Z - Z_S)}{r_{13}(X - X_S) + r_{23}(Y - Y_S) + r_{33}(Z - Z_S)}$$

where (x, y) is the sensor coordinates, (X, Y, Z) the ground coordinate, and f a focal length and (Xs, Ys, Zs) the coordinates of satellite position.

$r_{11} \sim r_{33}$ are coefficients of the rotation matrix to accord with the sensor coordinates. The rotation matrix is determined by rotation or Euler's angles, ω, φ and κ angles. This model is called a position-ration (PR) model. We tested several PR models using different sets of unknowns. Various unknown sets are shown in table 1.

ID	Unknown sets
PR-1	$X_0, a_1, b_1, Y_0, a_2, b_2, Z_0, a_3, b_3, \kappa_0, \varphi_0, \omega_0$
PR-2	$X_0, a_1, b_1, Y_0, a_2, b_2, Z_0, a_3, b_3, \kappa_0, a_4, b_4$
PR-3	$X_0, a_1, b_1, Y_0, a_2, b_2, Z_0, a_3, b_3$
PR-4	$\kappa_0, a_4, b_4, \varphi_0, a_5, b_5, \omega_0, a_6, b_6$
PR-5	$X_0, Y_0, Z_0, \kappa_0, \varphi_0, \omega_0$
PR-6	X_0, Y_0, Z_0
PR-7	$\kappa_0, \varphi_0, \omega_0$

Table 1. The Different Sets of Unknown of Collinearity-based Models

PR-1 used parameters of position, such as position bias, drift, acceleration, and the angle bias of ω_0, ϕ_0 and κ_0 angles. PR-2 modelled κ bias of the second order unknowns and PR-1 parameters excluding ω_0 and ϕ_0 angle bias. PR-3 has only PR-1 parameters except for angel bias. PR-4 has angle bias, drift and acceleration. PR-5 has position and angle bias. PR-6 has position bias. PR-7 has Angle bias.

3. ORBIT-BASED MODELS

Orbit-based models physically show better the geometric relation than collinearity-based models. Orbit-based model is represented by the following simple matrix equation

$$\begin{pmatrix} x \\ y \\ -f \end{pmatrix} = \lambda \mathbf{R}_{rpy}^{\mathbf{T}} \mathbf{R}_{\mathbf{P,V}}^{\mathbf{T}} \begin{pmatrix} X - X_S \\ Y - Y_S \\ Z - Z_S \end{pmatrix} \quad (2)$$

where (x, y) is the sensor coordinates, f a focal length, (X, Y, Z) the ground coordinate, (Xs, Ys, Zs) the coordinates of satellite position and λ a scale factor. R_{rpy} represents the rotation matrix determined by the attitude angles of roll, pitch and yaw angles. $R_{\overrightarrow{P,V}}$ represents position vectors $\vec{P}$ and velocity vectors $\vec{V}$ and the ration matrix determined by from the orbital frames to the ground control frames. Rotation matrix of Position, velocity and attitude angles for SPOT satellites are as bellow(SPOT Image,2002).

$$\mathbf{R}_{rpy} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos Pitch & \sin Pitch \\ 0 & -\sin Pitch & \cos Pitch \end{pmatrix} \begin{pmatrix} \cos Roll & 0 & -\sin Roll \\ 0 & 1 & 0 \\ \sin Roll & 0 & \cos Roll \end{pmatrix} \begin{pmatrix} \cos Yaw & -\sin Yaw & 0 \\ \sin Yaw & \cos Yaw & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (3)$$

$$\mathbf{R}_{\mathbf{P,V}} = \begin{pmatrix} X_X & Y_X & Z_X \\ X_Y & Y_Y & Z_Y \\ X_Z & Y_Z & Z_Z \end{pmatrix} \quad (4)$$

$$\begin{pmatrix} X_X \\ X_Y \\ X_Z \end{pmatrix} = \mathbf{X} = \frac{\mathbf{V} \times \mathbf{Z}}{\|\mathbf{V} \times \mathbf{Z}\|}, \quad \begin{pmatrix} Y_X \\ Y_Y \\ Y_Z \end{pmatrix} = \mathbf{Y} = \frac{\mathbf{Z} \times \mathbf{X}}{\|\mathbf{Z} \times \mathbf{X}\|}, \quad \begin{pmatrix} Z_X \\ Z_Y \\ Z_Z \end{pmatrix} = \mathbf{Z} = \frac{\mathbf{P}}{\|\mathbf{P}\|} \quad (5)$$

This model is called as an orbit-attitude, OA model. For OA models we tested with different sets of unknowns, as shown in table 2.

ID	Unknown sets
OA-1	$X_0, a_1, b_1, Y_0, a_2, b_2, Z_0, a_3, b_3, R_0, P_0, \Psi_0$
OA-2	$X_0, a_1, b_1, Y_0, a_2, b_2, Z_0, a_3, b_3, \Psi_0, a_9, b_9$
OA-3	$X_0, a_1, b_1, Y_0, a_2, b_2, Z_0, a_3, b_3$
OA-4	$R_0, \dot{R}, \ddot{R}, P_0, \dot{P}, \ddot{P}, \Psi_0, \dot{\Psi}, \ddot{\Psi}$
OA-5	$X_0, Y_0, Z_0, R_0, P_0, \Psi_0$
OA-6	X_0, Y_0, Z_0
OA-7	R_0, P_0, Ψ_0

Table 2. The Different Sets of Unknown of Orbit-Attitude Models

OA-1 had 12 parameters of position, such as position bias, drift, acceleration, and the attitude bias of R_0, P_0 and ψ_0 angles. OA-2 modelled roll bias, drift and acceleration unlike attitude bias of OA-1 and ψ_0 angle, drift and acceleration. OA-3 had the biases, drifts and accelerations of only the position. OA-4 modelled the biases, drift and accelerations of only the attitude angles and OA-5 simply only the position and attitude biases. OA-6 and OA-7 modelled more simply unknowns as position biases of OA-6 and attitude biases of OA-7.

4. INTERPOLATION

4.1 Lagrange Interpolation

For SPOT-3 satellite, 8-ephemeris data composed of the position and velocity of the satellites acquired every minute are provided. Position (Xs, Ys, Zs) and velocity (Vx, Vy, Vz) of satellite are interpolated from this ephemeris data using the Lagrange formula by the bellow;

$$\vec{P}(t) = \sum_{j=1}^{8} \frac{\vec{P}(t_j) \times \prod_{\substack{i=1 \\ i \neq j}}^{8} (t - t_i)}{\prod_{\substack{i=1 \\ i \neq j}}^{8} (t_j - t_i)} \quad \vec{V}(t) = \sum_{j=1}^{8} \frac{\vec{V}(t_j) \times \prod_{\substack{i=1 \\ i \neq j}}^{8} (t - t_i)}{\prod_{\substack{i=1 \\ i \neq j}}^{8} (t_j - t_i)} \quad (6)$$

where $P(t_i)$ is the position coordinates of the satellites at time t_i and $V(t_i)$ the velocity coordinates of the satellites at time t_i(SPOT Image, 2002).

4.2 Piecewise-Linear Interpolation

The attitude accelerations of roll, pitch and yaw angles for SPOT are offered by each line-interval of 8Hz. If the attitude values assume as zero at the beginning line of image, the attitude of the lines measured by attitude sensors can be computed using integration of attitude rates. Then, attitude angles for any image line can be calculated by linearly interpolating the attitude angles at the neighboring two image lines measured by attitude sensors.

5. RESULT

5.1 Dataset

The top of scene is Chuncheon, and the others scenes are Yangpeong, Cheonan, Daejeon, Junju, Kwangju and Naju with the length of 420 Km.

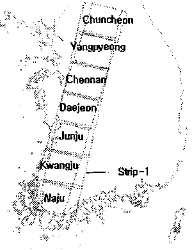

Figure 1. The location of image strip-1

Table 3 show GCPs used for this research.

ID	Strip-1
No. of Chuncheon GCPs	16
No. of Yangpeong GCPs	22
No. of Cheonan GCPs	26
No. of Daejeon GCPs	27
No. of Junju GCPs	25
No. of Kwangju GCPs	23
No. of Naju GCPs	18

Table 3. The Number of GCPs

5.2 Individual Scene Modelling with Different Sets of Unknowns

To get the proper sets of unknowns for PR and OA models, we modelled parameters represented by table 1 and 2. Every PR 1~7 and OA 1~7 models were established for one scene covering the Daejeon. The results are shown in Table 4.

Model	Daejeon (pixels)	Model	Daejeon (pixels)
PR-1	1.187	OA-1	1.194
PR-2	1.179	OA-2	1.195
PR-3	2.369	OA-3	2.369
PR-4	1.617	OA-4	1.620
PR-5	1.085	OA-5	1.089
PR-6	2.085	OA-6	2.072
PR-7	1.243	OA-7	1.281

Table 4. PR and OA Models established in Daejeon

The performance of PR and OA models for one scene was similar to each other to each other for the same set of unknowns.

5.3 Modelling Satellite Image Strips

Figure 1 shows the location of the image strip we used for experiments. The aim of our research has a focus on testing the feasibility of modelling whole satellite image strips by establishing sensor models of one scene with GCPs. For this, we found appropriate sensor models of entire image strips composing of several adjacent scenes using PR and OA models. We represented two methods. First, we established PR and OA models with the top scene of strip-1, Chuncheon and then with the bottom scene of strip-1, Naju.

Results show that for PR1~4 and OA1~4 the more the distance between model scenes and the scene under tests the more rapidly the errors of sensor models increased (see Table 5 and 6). The number of tables is the errors of the modelling. The unit use pixel.

Scene ID	PR-1	PR-2	PR-3	PR-4	PR-5	PR-6	PR-7
Chuncheon	4.147	3.963	3.647	2.585	1.522	1.401	1.214
Yangpeong	34.747	31.841	55.297	25.027	3.164	1.893	1.430
Cheonan	131.456	146.849	237.793	90.590	5.106	2.253	1.601
Daejeon	353.452	411.467	660.498	234.146	7.372	2.124	1.959
Junju	674.701	1001.737	1296.460	453.963	9.928	2.094	2.643
Kwangju	1008.519	2959.233	2109.703	715.707	12.060	2.817	2.231
Naju	1746.667	6572.926	3507.150	1151.651	13.992	2.898	3.075

Table 5. Orbit Modelling Errors for PR 1~7 (in pixel)

Scene ID	OA-1	OA-2	OA-3	OA-4	OA-5	OA-6	OA-7
Chuncheon	4.095	3.835	3.503	2.590	1.568	1.407	1.137
Yangpeong	36.333	35.798	53.262	23.249	3.293	1.871	1.412
Cheonan	141.294	148.741	228.409	78.255	5.362	2.204	1.491
Daejeon	401.540	419.649	670.025	185.216	7.821	2.038	1.468
Junju	823.792	870.435	1422.607	321.708	10.615	1.981	1.583
Kwangju	1171.180	1275.708	2249.416	415.178	13.282	2.576	1.767
Naju	2494.448	3728.853	4778.138	605.336	15.406	2.588	1.865

Table 6. Orbit Modelling Errors for OA 1~7 (in pixel)

PR-5~7 and OA-5~7 showed better results. Their errors increased linearly as the distance from the Chuncheon scene. OA-7 appeared as the fittest sensor model among the models tested to model image strips of the length of 420 Km.

The capability of sensor models using whole images strip was analyzed by changing the location of the modelling scene. The former experiments used the top scene of strip. At this time, we carried out experiments with the bottom scene of strip, Naju. Table 7 and 8 is these results.

SceneID	PR-1	PR-2	PR-3	PR-4	PR-5	PR-6	PR-7
Chuncheon	131.608	1022.288	148.392	641.274	8.118	2.127	2.650
Yangpeong	86.384	440.206	97.314	368.477	6.695	2.121	2.604
Cheonan	55.485	228.981	62.377	209.429	5.382	2.400	2.267
Daejeon	29.734	99.143	33.254	93.343	3.875	2.183	1.718
Junju	12.100	29.117	13.478	28.140	3.006	2.195	1.526
Kwangju	3.082	6.544	4.202	8.392	2.058	1.685	1.606
Naju	0.957	0.957	1.378	1.151	0.983	1.410	1.243

Table 7. PR –1 to 7 established in Naju
and applyed the Models to Neighboring Scenes (in pixel)

SceneID	OA -1	OA -2	OA -3	OA -4	OA -5	OA -6	OA -7
Chuncheon	129.734	156.348	144.867	154.102	7.793	1.878	1.764
Yangpeong	85.346	117.611	95.341	114.518	6.514	1.973	1.794
Cheonan	54.955	84.862	61.316	85.759	5.237	2.291	1.693
Daejeon	29.524	43.182	32.813	44.489	3.782	2.099	1.451
Junju	12.058	12.925	13.354	13.338	2.957	2.133	1.668
Kwangju	3.099	6.132	4.184	6.154	2.080	1.679	1.495
Naju	0.957	0.940	1.378	1.158	0.982	1.412	1.219

Table 8. OA –1 to 7 established in Naju and applyed the Models to Neighboring Scenes (in pixel)

We apphed the sensor models established in Naju to the other scenes. Again OA-7 showed the best performance and established orbit modelling with errors almost independent to the location. Figure 2 and 3 shows the performance of orbit modelling as functions of the location within the strip.

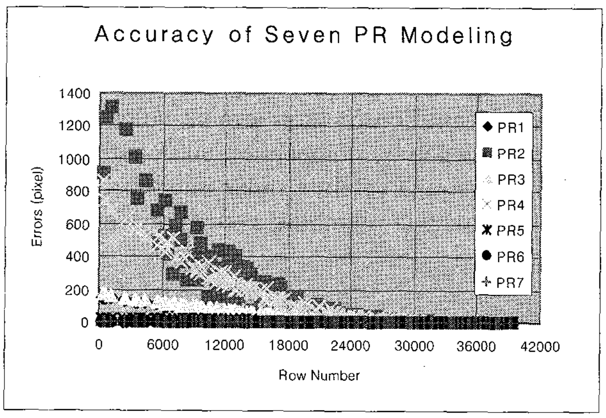

Figure 2. PR Models established in Naju by using Whole Image Strip

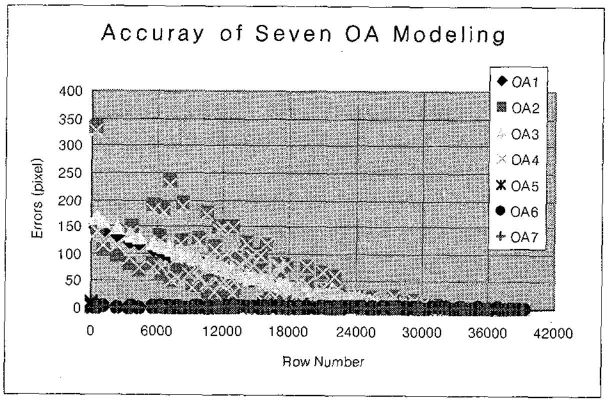

Figure 3. OA Models established in Naju by using Whole Image Strip

6. DISCUSSIONS

We usually use control ground points for the sensor model. This requirement increases the cost and the processing time. This paper represented a method of establishing models for the whole orbit so that not all individual scenes require ground control points.

Interpolation of velocity and position used Lagrange polynomial, interpolation of attitude piecewise linear method. The appropriate parameters were found by carrying out sensor modelling of the different sets of unknowns. We tested the models using image segments of 420 Km . Sensor models were remarkably sensitive to different sets of unknowns. All PR and OA models were feasible for one scene modelling. However, the only PR-6, 7 and OA-6, 7 were feasible for orbital modelling. And OA-7 was the most appropriate sensor model for modelling the whole images.

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