Investigation of Sensor Models for Precise Geolocation of GOES-9 Images

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ABSTRACT:

A numerical formula that presents relationship between a point of a satellite image and its ground position is called a sensor model. For precise geolocation of satellite images, we need an error-free sensor model. However, the sensor model based on GOES ephemeris data has some error, in particular after Image Motion Compensation (IMC) mechanism has been turned off. To solve this problem, we investigate three sensor models: Collinearity model, Direct Linear Transform (DLT) model and Orbit-based model. We apply matching between GOES images and global coastline database and use successful results as control points. With control points we improve the initial image geolocation accuracy using the three models. We compare results from three sensor models that are applied to GOES-9 images. As a result, a suitable sensor model for precise geolocation of GOES-9 images is proposed.

KEYWORDS: GOES-9, Sensor Model, Collinearity, DLT, Orbit-Attitude Model.

1. Introduction

Korea will launch the geostationary satellite called Communication, Oceanography and Meteorology Satellite (COMS) in 2008. The COMS will observe ocean and earth atmosphere and send observation images to ground users. For precise analysis, geolocation accuracy of acquired information from images is important. In other words, satellite image points must be precisely projected on target ground points. This process is called georeferencing or geolocation and the accuracy of geolocation is deeply associated with the accuracy of satellite orbit and attitude knowledge.

For this reason, some geostationary satellites such as GOES, NOAA, MTSAT-1R includes the process called 'image navigation' for ground preprocessing. Image navigation is the process of determining the navigational parameters of satellite from images (Kamel, 1996). Image navigation will also be included in ground processing of the COMS.

A numerical formula that presents relationship between a point of a satellite image and its ground point is called a sensor model. A sensor model influences the accuracy of image navigation. However, the sensor model based on GOES ephemeris data and the formula provided in ELUG document (NOAA/NESDIS, 1998) has some error, in particular after IMC mechanism has been turned off. To solve this problem, we investigate three sensor models that can correct such errors through bundle adjustments; collinearity model, DLT model and orbit-based model. We apply these sensor models on GOES images to find a suitable sensor model. As a result, we will propose appropriate sensor model for ground preprocessing of the COMS.

We prepare control points required for bundle adjustments by apply matching between GOES images and global coastline database. We choose successful match results as control points and using them we improve the initial geolocation accuracy.

2. Sensor models

2.1 Collinearity Model

Collinearity Model is based on traditional collinear equation mainly used in aerial photogrammetry. We can express the model as below.

$$\begin{pmatrix} u_1 \\ u_2 \\ u_3 \end{pmatrix} = R \begin{pmatrix} X - Xs \\ Y - Ys \\ Z - Zs \end{pmatrix} \tag{1}$$

In above equation (1), unit vector (u1, u2, u3) is image look vector and (X, Y, Z) ground coordinate, (Xs, Ys, Zs) the position of the satellite. The matrix R is rotation matrix matches sensor and ground coordinate. This model is also called 'Position-Rotation Model' (Kim, 2005).

2.2 Direct Linear Transform (DLT) Model

Direct Linear Transform (DLT) model is an abstract model usually used in computer vision. We use the equation that Gupta and Hartley(1997) proposed as below.

$$\begin{pmatrix} wc \\ wr \\ w \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \tag{2}$$

where (c, r) is an image coordinate

w is a scale factor

(X, Y, Z) is a ground coordinate

DLT model gets image coordinate directly from ground point (X, Y, Z). Therefore DLT can offer fast operation.

2.3 Orbit-based Model

Collinearity model simplifies the relation between image coordinates and ground coordinates by the three rotation angles. Actually, the orbit coordinate system is time-dependent and is defined by the position and velocity vector of a satellite. And a satellite is deviated from the orbit coordinate system by the amount of attitude angles. To describe actual imaging geometry of satellite on its orbit, we may use position, velocity vector and attitude angles. Sensor model based on the above terms is shown below.

$$\begin{pmatrix} u_1 \\ u_2 \\ u_3 \end{pmatrix} = \lambda R^T{}_{rpy} R^T{}_{\vec{P},\vec{V}} \begin{pmatrix} X - Xs \\ Y - Ys \\ Z - Zs \end{pmatrix} \tag{3}$$

where (Xs, Ys, Zs) is ground position

rpy is Roll, Pitch, Yaw; attitude angle

$\vec{P}, \vec{V}$ is position and velocity vector

In formula (3), R_{rpy} is rotational matrix determined by roll, pitch and yaw. And $R_{P,V}$ is also rotational matrix represented by position and velocity vector. λ is ratio constant.

3. Experiments

3.1 Control Points

In these experiments, we used channel 2 IR images extracted from GOES Variable (GVAR) raw data. Only results using three images are shown here. For precise correction, two types of control points are used. One type is calculated from GVAR initial sensor models. They are used to verify whether the three models can substitute the model provided by ELUG (We call them as 'GVAR GCP'). The second type is obtained by applying match between GOES images and global coastline database and by choosing successful results (Lee et al., 2005). They are used to remove geolocation errors contained in the initial sensor model (We call them as 'RANSAC GCP'). GVAR GCPs consist of 50 pts. and RANSAC GCPs consist of 7-8 pts..

3.2 Method

For each sensor model, we first estimate model parameters by using GVAR GCP. After that, modeling accuracy was calculated. These processes are to verify these models can approximate sensor models for GOES-9 images.

Second, we estimate model parameters with RANSAC GCP. We project global shoreline database onto GOES-9 images using each sensor model. By this way, we verify whether sensor models can be used for precise correction.

3.3 Results and Discussion

Table 1 shows results of modeling accuracy using GVAR GCPs. Listed values are root mean square errors (RMSE, in pixels).

This shows each model is suitable to substitute the sensor model of GOES-9 images provided by ELUG. Errors of all models are almost same.

	Collinearity	DLT	Orbit-based
2004.04.21 07:25:00	1.140175	1.14864	1.264911
2004.10.21 02:25:00	1.191638	1.161306	1.16619
2004.10.21 20:25:00	1.174734	1.202853	1.183216

Table 1. RMSE using GVAR GCPs

Table 2 shows also RMSE using RANSAC GCPs.

	Collinearity	DLT	Orbit-based
2004.04.21 07:25:00	1.541104	0.307459	1.541104
2004.10.21 02:25:00	2.03101	0.304882	1.732051
2004.10.21 20:25:00	2.329929	0.347135	1.927248

Table 2. RMSE using RANSAC GCPs

Table 2 shows that RMSE of DLT model is smaller than that of other models. If we consider the magnitude of RMSE only, DLT may appear preferable. However, we may get different ideas, when we plot the global coastline data onto GOES images using different models.

Figure 1. Projection results using initial model

Figure 1 shows that initial model was projected successfully on the northern hemisphere (left two clips), but in the southern hemisphere, coastline mismatched.

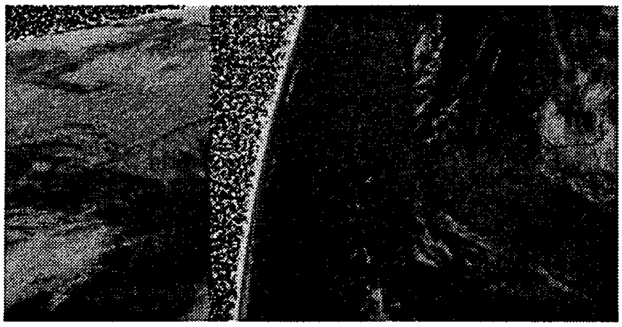

Figure 2. Projection results using collinearity model

Using collinearity was properly projected in both hemispheres.

Figure 3. Projection results using DLT model

DLT shows more accurate results. But, DLT has much more errors in edge of circle (left two clips).

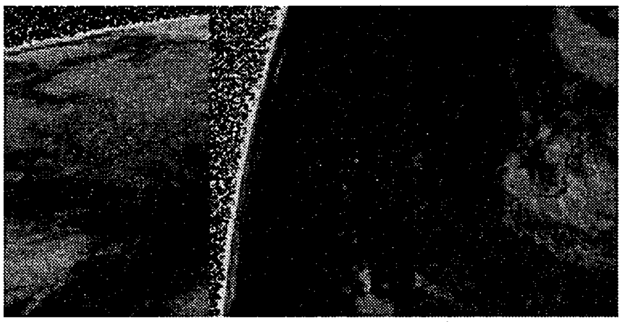

Figure 4. Projection results using orbit-based model

Orbit-based shows almost same results with collinearity.

Conclusions

In this paper, we investigated three models; collinearity, DLT and orbit-based. With two types of control points, we verified each model is suitable for GOES-9 images and precise correction. Finally, we decided that orbit-based model is suitable sensor model for precise geolocation of GOES-9 images through the results. Also, the model is useful for ground preprocessing of the COMS.

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