CAMERA MODELING OF LINEAR PUSHBROOM IMAGES: PERFORMANCE ANALYSIS

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ABSTRACT :

In this paper, we introduce a more improved camera modeling method for linear pushbroom images than the method proposed by Orun and Natarajan(ON). ON model shows an accuracy of within 1 pixel if more than 10 ground control points(GCPs) are provided. In general, there is high correlation between platform position and attitude parameters but ON model ignores attitude variation in order to overcome such correlation. We propose a new method that obtains an optimal solution set of parameters without ignoring the attitude variation. We first assume that attitude parameters are constant and estimate platform position's. Then we estimate platform attitude parameters using the values of estimated position parameters. As a result, we can set up an accurate camera model for a linear pushbroom satellite scene. In particular, we can apply the camera model to its surrounding scenes because our model provide sufficient information on satellite's position and attitude not only for a single scene but also for a whole imaging segment. We tested on two images: one with a pixel size 6.6m×6.6m acquired from EOC(Electro Optical Camera), and the other with a pixel size 10m×10m acquired from SPOT. Our camera model procedures were applied to the images and gave satisfying results. We had obtained the root mean square errors of 0.5 pixel and 0.3 pixel with 25 GCPs and 23 GCPs, respectively.

1. INTRODUCTION

Pushbroom images have a number of geometric distortions. These are due to the factors such as satellite orbit and attitude variations, sensor geometry, etc. Accurate camera modeling is required for geometric correction of the distorted data. Up until now, several camera modeling methods have been suggested, such as ones using the photogrammetric collinearity equations and orbit geometry. ON's model is also based on collinearity equations. In general, there is high correlation between platform position and attitude parameters but ON model ignores attitude variation in order to overcome such correlation. We propose a new method that obtains an optimal solution set of parameters without ignoring the attitude variation. Our model is conceptually similar to ON's, but because of the different standpoint, the details are some what different. We want to apply the camera modeling not only for a single scene, but also for nearby scenes. With ON's model this was not feasible, but our model overcomes this issue because for it provides sufficient information on the satellite's position and attitude.

In section 2, we explain ON's model. In this paper, we concentrate on photogrammetric collineartiy equations. We illustrate in detail our camera modeling in section 3. In section 4 and 5, we discuss about the result of performance test. Lastly, we illustrate some further work and conclusions in section 6.

2. ORUN AND NATARAJAN'S MODEL

Orun and Natarajan's model(Orun and Natarajan, 1994) is primarily based on a photogrammetric collinearity equations. A photogrammetric collinearity equations model is a camera modeling system originally developed for perspective images and they modified the model for linear pushbroom images. Suppose for a given time t, there exists a earth-centered coordinate system(S) and a satellite-centered coordinate system(C).

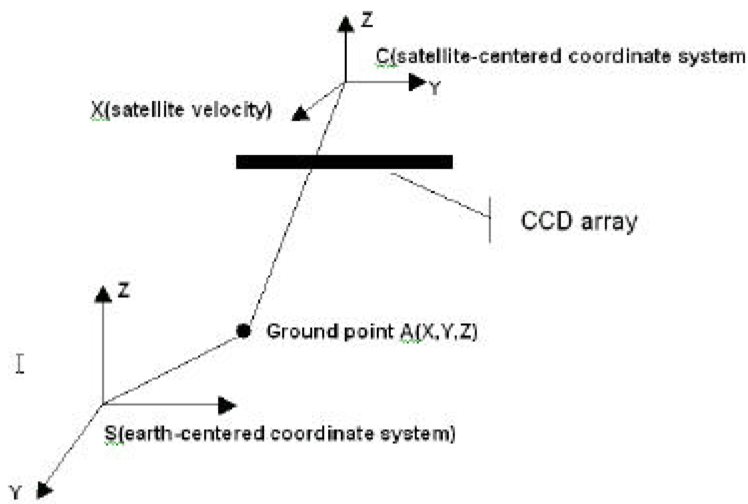

Fig.1. Geometry between spaceborne camera and earth-centered Cartesian coordinate, used for the Orun and Natarajan model.

A point (X,Y,Z) based on S, the earth-centered coordinate system and another point (0, y-f) on a CCD array of a satellite based on C, the satellite-centered coordinate system can be shown as below.

$$x = 0 = -f\frac{r_{11}(X - X_0) + r_{21}(Y - Y_0) + r_{31}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z0)} \qquad (2.1)$$

$$y = -f\frac{r_{12}(X - X_0) + r_{22}(Y - Y_0) + r_{32}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z0)} \qquad (2.2)$$

Here, the point, (X_0, Y_0, Z_0) is the origin of the satellite-centered coordinate system translated to the earth-centered coordinate system, at a given time. $r_{11} \sim r_{33}$ are values of rotation conversion R that translates the satellite-centered coordinate system into earth-centered coordinate system. Given that the satellite-centered coordinate system, C has rotated in the amount of ?,f , ? in the order of Z, Y and X axis, R can be shown as below.

R =

$$\begin{bmatrix} \cos(\varphi)*\cos(\kappa), & -\cos(\varphi)*\sin(\kappa), & \sin(\varphi) \\ \sin(\omega)*\sin(\varphi)*\cos(\kappa)+\cos(\omega)*\sin(\kappa), & -\sin(\omega)*\sin(\varphi)*\sin(\kappa)+\cos(\omega)*\cos(\kappa), & -\sin(\omega)*\cos(\varphi) \\ -\cos(\omega)*\sin(\varphi)*\cos(\kappa)+\sin(\omega)*\sin(\kappa), & \cos(\omega)*\sin(\varphi)*\sin(\kappa)+\sin(\omega)*\cos(\kappa), & \cos(\omega)*\cos(\varphi) \end{bmatrix}$$

The equations (2.1) and (2.2) are very similar to that of collinearity equations of perspective images. They differ with x being converted to 0 on the left hand side of the equation (1), due to the characteristics of pushbroom cameras. However, in case of satellite imaging of pushbroom cameras, the camera coordinate system C is captured moving along the path of the satellite, the position of the satellite (X_0, Y_0, Z_0) and the rotation movement matrix $r_{11} \sim r_{33}$ are not constant values but functions of time or x.

Gugan and Dowman modelled the position of the satellites (X_0, Y_0, Z_0) and the attitude of the satellite ?,f , ? into a 2nd order differential equation of time, as below(Gugan and Dowman,1998). In the equations below, time, t can be replaced by the coordinate value of the image, x.

$$X_s = X_0 + a_1 t + b_1 t^2 \qquad Y_s = Y_0 + a_2 t + b_2 t^2$$

$$Z_s = Z_0 + a_3 t + b_3 t^2 \qquad \kappa = \kappa_0 + a_4 t + b_4 t^2 \qquad (2.3)$$

$$\varphi = \varphi_0 + a_5 t + b_5 t^2 \qquad \omega = \omega_0 + a_6 t + b_6 t^2$$

The procedure above has been introduced previously, especially as camera modeling on the SPOT image and many other theses adopted similar models (Konecny et al., 1987).

The mathematical models shown above may look as though they have no problems, but many have been pointed out. The biggest problem is that, when obtaining the observation matrix using the Least Square Method of this model, there occurs a large mutual correlation between the rows of the observation matrix, causing the Rank of the matrix becomes much smaller than the number of parameters. In this case, the solution can not be obtained using the general Least Square Method. The reason for this phenomenon is because there exists a mutual correlation of the change direction X and the angle f , with the change of direction Y and the angle ?, as Orun and Natarajan have already indicated (Orun and Natarajan, 1994).

To overcome this problem, Orun and Natarajan presented another model as below. Pitch and roll, p and w each, are set to be time-independent values, and 4 other variables are in 2nd order equations of time.

$$X_s = X_0 + a_1 t + b_1 t^2 \quad Y_s = Y_0 + a_2 t + b_2 t^2$$

$$Z_s = Z_0 + a_3 t + b_3 t^2 \quad \kappa = \kappa_0 + a_4 t + b_4 t^2 \qquad (2.4)$$

The model above will be referred to as the ON(Orun and Natarajan) model.
There are 12 unknowns in the ON model, and the least number of GCPs for obtaining the solution using the Least Square Method is 6. (Kim, 2000)

3. NEWLY PROPOSED METHOD

We are already aware of the fact that using 10~12 GCPs, we can easily make the R.M.S error to converge into within 1 pixel on a scene, using the ON model (Kim, 2000). However, because we have set the attitude values to be time-independent constants, we can not apply this camera model on adjacent scenes. Furthermore, we can not establish camera modeling on inaccessible areas where we can not obtain GCP. Therefore, the model we have proposed must be used after isolating the mutually correlated variables and obtaining of the values matching the position variables, followed by obtaining the values matching the attitude variables of the time.

We shall examine in two separate stages. First is the same as the calculation of the ON model. ?,f , ? are set as time-independent values and the 4 other variables are modeled as 2nd order equations of time.

$$X_s = X_0 + a_1 t + b_1 t^2$$

$$Y_s = Y_0 + a_2 t + b_2 t^2 \qquad (3.1)$$

$$Z_s = Z_0 + a_3 t + b_3 t^2$$

The solution is calculated using the Least Square Method about the 9 unknowns (X_0, Y_0, Z_0, $a_1, a_2, a_3, b_1, b_2, b_3$). Next, fix the position variables of the satellite obtained from above, and find the 2nd order modeled values of the satellite's attitude variables.

$$t \quad \kappa = \kappa_0 + a_4 t + b_4 t^2$$

$$\varphi = \varphi_0 + a_5 t + b_5 t^2$$

$$\omega = \omega_0 + a_6 t + b_6 t^2 \qquad (3.2)$$

The solution is calculated again using the Least Square Method about the 10 unknowns (t, $?_0$, $?_0$, $?_0$, $a_4, a_5, a_6, b_4, b_5, b_6$). Calculating separately, no effect will be faced from the correlation of the variables. It has been modeled for all the variables as 2nd order equations of time, resulting not only in that precise values will be obtained, but also cameras can be set at any nearby areas.

4. PERFORMANCE TEST

We tested on two images: one with a pixel size 6.6m×6.6m acquired from EOC(Electro Optical Camera), and another with pixel size 10m×10m acquired from SPOT. Some of total Ground Control Points(GCPs) is used to set up camera modeling and the remaining GCPs is used as an independent analysis of the accuracy of camera modeling. To check the relation between the number of GCPs using camera modeling and the accuracy, we repeat the tests with various the number of GCPs.

No. of GCPs		Modeling Errors (RMS errors, Pixel)	Independent Test (RMS errors, Pixel)
No. of GCPs using a Modeling	No. of GCPs using an independent test		
6	19	0.07	12.43
7	18	0.15	4.73
8	17	0.12	1.71
9	16	0.28	1.95
10	15	0.32	1.80
11	14	0.31	0.90
12	13	0.34	1.01
13	12	0.31	1.05
14	11	0.36	0.96
15	10	0.34	1.03
16	9	0.33	1.21
17	8	0.36	1.43
18	7	0.37	1.28
19	6	0.35	1.31
20	5	0.38	0.99
21	4	0.38	0.56
22	3	0.40	0.58
23	2	0.41	0.64
24	1	0.42	0.58
25	0	0.41	N/A

Table 1. Performance of our model on EOC imagery.

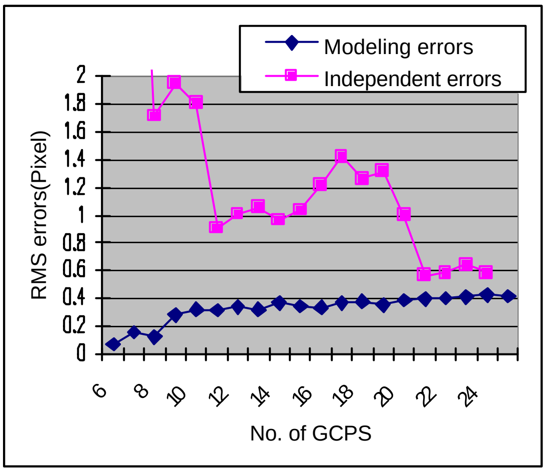

Fig 2. chart for Table 1.

No. of GCPs		Modeling Errors (RMS errors, Pixel)	Independent Test (RMS errors, Pixel)
No. of GCPs using a Modeling	No. of GCPs using an independent test		
6	17	0.02	20.57
7	16	0.02	1.90
8	15	0.14	1.55
9	14	0.31	2.77
10	13	0.24	1.41
11	12	0.33	0.87
12	11	0.44	1.30
13	10	0.27	0.77
14	9	0.26	0.81
15	8	0.26	0.70
16	7	0.24	0.76
17	6	0.32	0.96
18	5	0.33	0.87
19	4	0.33	0.69
20	3	0.42	0.85
21	2	0.42	0.50
22	1	0.42	0.54
23	0	0.43	N/A

Table 2. Performance of our model on SPOT imagery.

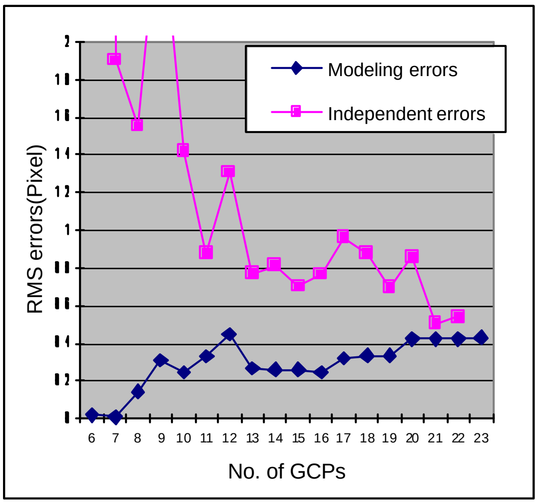

Fig 3. chart for Table 2.

5. DISCUSSION OF RESULTS

The performance analysis results presented on Table 1 and 2. Theoretically, 6 standard points, which is the least number to find the solution, should be enough for establishing the camera model. As the number of standard points for the modeling increases, the error of those points increased and that of independent standard points decreased. Nevertheless, applying more than 10 standard points, the figure did not have too much effect on the accuracy. Based upon this fact, we can conclude that we obtain a sufficiently accurate camera model using 10~12 standard points. Fig .2,3 shows the inverse-correlation between the error of the standard points used for modeling and that of independent standard points, and that as the number of standard points used for modeling increased, both the modeling error and the independent error converge into within a pixel. Also, we established camera model in adjacent areas. We set up camera modeling in Daejeon city, Repubic of Korea, and then apply the camera modeling to Jeonju - the remote city from Daejeon. All checkpoints have an accuracy of within 0.5 pixel in Jeonju.

6. CONCLUSIONS

The emphasis of this paper put upon the settlement of ambiguity in the attitude values, which is one of the demerits of ON's model. Furthermore, we can now establish camera model in adjacent areas. As a result of sufficient data about the position and the attitude of the satellite, the more precise camera model could be established. We tested on two images: one with a pixel size 6.6m×6.6m acquired from EOC(Electro Optical Camera), and the other with a pixel size 10m×10m acquired from SPOT. Our camera model procedures were applied to the images and gave satisfying results. We had obtained the root mean square errors of 0.5 pixel and 0.3 pixel with 25 GCPs and 23 GCPs, respectively.

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