A STUDY ON DEM GENERATON USING POLYNOMIAL CAMERA MODEL IN SATELLITE IMAGERY

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Abstract- **Nowadays the Rational Function Model (RFM), an abstract sensor model, is substituting physical sensor models for highly complicated imaging geometry. But RFM is algorithm to be required many Ground Control Points (GCP). In case of RFM of the third order, At least forty GCP are required for RFM generation. The purpose of this study is to research more efficient algorithm on GCP and accurate algorithm similar to RFM. The Polynomial Camera Model is relatively accurate and requires a little GCP in comparisons of RFM. This paper introduces how to generate Polynomial Camera Model and fundamental algorithms for construction of 3-D topographic data using the Polynomial Camera Model information in the Kompsat stereo pair and describes how to generate the 3-D ground coordinates by manual matching. Finally we tried to extract height information for the whole image area with the stereo matching technique based on the correlation.**

***Keyword*: satellite sensor, satellite image, camera model**

1. INTRODUCTION

Recently Research for generation Camera Model which is proper for Satellite Imagery has been continued. In particular Research for Abstract Sensor Model with Physical Sensor Model has been developed and the try to apply algorithm such as Perspective, DLT (Direct Linear Transform) and Affine Camera Model is continued. But these algorithms have to be require to prove again when apply to the other Satellite Image. Therefore general Camera Model's development is required .In last a few years Rational Function Model (RFM) is developed as general camera model for Satellite Image Many of the common cameras such as Perspective, DLT, Affine may be considered as special cases of the RFM and it is known for RFMs Performance to be very excellent. But to generation RFM we need too many GCPs. For example DLT algorithm is required over at least 6 points and Affine Camera over at least 4 points but RFM over at least 40 points in case of the third order. Because the least square algorithm is used in order to optimize RFM, RFM actually need over 50 GCPs. But Polynomial Camera is just required a half number of GCPs of RFM and performance is similar to RFM.

In this study, we will introduce how to generate Polynomial Camera Model and reconstruct 3D World Coordinate from stereo pair and find the epipolarity

2. POLYNOMIAL CAMERA

Polynomial Camera Model is also in special case of RFM. RFM is define as following

$$row = \frac{Num_R(X,Y,Z)}{Den_R(X,Y,Z)} \qquad col = \frac{Num_C(X,Y,Z)}{Den_C(X,Y,Z)} \tag{2-1}$$

Where row is the row of Image Coordinate

col is the column of Image Coordinate

X, Y, Z are World Coordinate

Num (·) and Den (·) are homogeneous polynomials of the n-orders

In Case of denomial be constants (2-1) will be Polynomial Camera Model and extension from Affine Camera Model.

Polynomial Camera Model is defined as following

$$row = \sum_{i=0,j=0,k=0}^{i=n1,j=n2,k=n3} a_{ijk} X^i Y^j Z^k$$
$$col = \sum_{i=0,j=0,k=0}^{i=n1,j=n2,k=n3} b_{ijk} X^i Y^j Z^k \qquad (2\text{-}2)$$

Where a_{ijk} the Coefficient of Polynomial Camera Model for row of image

b_{ijk} the Coefficient of Polynomial Camera Model for column of image

n1, n2, n3 are the order of Polynomial Camera

Equation (2-2) is the same as the numerator of Equation (2-1). Generation Polynomial Camera Model means to solve the Coefficients a_{ijk} and b_{ijk} of equation (2-2).

3. SOLVING FOR THE POLYNOMIAL CAMERA

3.1. GCP Data Normalization

We now consider the estimation problem for Polynomial Camera. First, we must consider GCP Data Normalization. GCP Data Normalization is used for improving a poor condition by scaling problem of World Coordinate X, Y, Z of GCP. This is a necessary process to achieve more good performance of all abstract Camera Models such as Perspective, DLT, Affine, RFM and Polynomial Camera Model. GCP Data Normalization can be implemented by translation and scaling of data and In this study, GCP Data Normalization was done with Unit Variance and Zero Mean. Implementation is following

$$Normalized\ Data = (Data - mean(Data)) * sqrt(1/\mathrm{var}(Data)) \qquad (3\text{-}1)$$

Where mean (data) is the Mean value of Data

var (data) is the Variance value of Data

sqrt (·) is the Square root

3.2. Solving Polynomial Camera Coefficient

Above mentioned, Generation Polynomial Camera means to solve the Coefficient a_{ijk} and b_{ijk} of equation (2-2). User can select the order of each World Coordinate X,Y,Z and these order selected by user is limited up to 3 order. Each term of Polynomials is also limited to (i+j+k)<= Maximum order which is selected by user. If the number of GCP is N and the term number of equation selected is T, equation (2-2) is defined as follow matrix equation.

$$\begin{bmatrix} 1 & Z_1 & Y_1 & \dots & X_1^T \\ 1 & Z_2 & Y_2 & \dots & X_2^T \\ 1 & Z_3 & Y_3 & \dots & X_3^T \\ 1 & Z_4 & Y_4 & \dots & X_4^T \\ . & . & . & \dots & . \\ . & . & . & \dots & . \\ . & . & . & \dots & . \\ 1 & Z_N & Y_N & \dots & X_N^T \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ . \\ . \\ a_T \end{bmatrix} = \begin{bmatrix} row_1 \\ row_2 \\ row_3 \\ row_4 \\ . \\ . \\ . \\ row_N \end{bmatrix} \qquad (3\text{-}2)$$

$$\begin{bmatrix} 1 & Z_1 & Y_1 & \dots & X_1^T \\ 1 & Z_2 & Y_2 & \dots & X_2^T \\ 1 & Z_3 & Y_3 & \dots & X_3^T \\ 1 & Z_4 & Y_4 & \dots & X_4^T \\ . & . & . & \dots & . \\ . & . & . & \dots & . \\ . & . & . & \dots & . \\ 1 & Z_N & Y_N & \dots & X_N^T \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ . \\ . \\ b_T \end{bmatrix} = \begin{bmatrix} col_1 \\ col_2 \\ col_3 \\ col_4 \\ . \\ . \\ . \\ col_N \end{bmatrix} \qquad (3\text{-}3)$$

Where $a_1 \dots a_T, b_1 \dots b_T$ are Polynomials Coefficients

Equation (3-2) and (3-3) are represented as following

$$\mathbf{G} \cdot \mathbf{A} = \mathbf{R}$$
$$\mathbf{G} \cdot \mathbf{B} = \mathbf{C} \qquad (3\text{-}4)$$

Where G: Matrix composed of World Coordinates

A, B: Vectors composed of Coefficients

R, C: Vectors composed of Image Coordinates

Using Least Square Method, we can solve A and B

$$\mathbf{A} = (\mathbf{G}^{\mathrm{T}} \cdot \mathbf{G})^{-1} \cdot \mathbf{G}^{\mathrm{T}} \cdot \mathbf{R}$$
$$\mathbf{B} = (\mathbf{G}^{\mathrm{T}} \cdot \mathbf{G})^{-1} \cdot \mathbf{G}^{\mathrm{T}} \cdot \mathbf{C} \qquad (3\text{-}5)$$

3.3. Extraction Epipolarity From Polynomial Camera Model Using Linearization of Nonlinear Equation And Limitation to Height Information

Before Stereo Matching, the epipolarity must be defined using Polynomial Camera Coefficients solved previously. It is simple to mathematically define Epipolarity of the first order Polynomial Camera (is similar to Affine Camera Model) but very difficult to define the high order Polynomial Camera Epipolarity.

Here, we will consider the epipolarity which can be defined even if any order of Polynomial Camera is selected. The epipolarity of high order Polynomial Camera can be determined by using linearization of nonlinear equation and limitation to height information.

First, using Taylor series, equation (2-2) can be rewritten as following

$$row = F_1(X,Y,Z) = \sum_{i=0,j=0,k=0}^{i=n1,j=n2,k=n3} a_{ijk} X^i Y^j Z^k$$
$$col = F_2(X,Y,Z) = \sum_{i=0,j=0,k=0}^{i=n1,j=n2,k=n3} b_{ijk} X^i Y^j Z^k \qquad (3\text{-}6)$$

$$F_{1\_0} + (\frac{\partial F_1}{\partial X})dX + (\frac{\partial F_1}{\partial Y})dY + (\frac{\partial F_1}{\partial Z})dZ = row$$
$$F_{2\_0} + (\frac{\partial F_2}{\partial X})dX + (\frac{\partial F_2}{\partial Y})dY + (\frac{\partial F_3}{\partial Z})dZ = col \qquad (3\text{-}7)$$

Where, F_{1_0} is the initial value of F_1

F_{2_0} is the initial value of F_2

$\frac{\partial}{\partial X}, \frac{\partial}{\partial Y}, \frac{\partial}{\partial Z}$ are partial difference for each World Coordinates X, Y, Z

In (3-7), a Z value, height information, is fixed by $Z_{\min}$ and $Z_{\max}$

$$F_{1\_Z=\min} + (\frac{\partial F_1}{\partial X})dX + (\frac{\partial F_1}{\partial Y})dY = row\_left$$
$$F_{2\_Z=\min} + (\frac{\partial F_2}{\partial X})dX + (\frac{\partial F_2}{\partial Y})dY = col\_left \qquad (3\text{-}8)$$

Where, row_left and col_left are Image Coordinate points of stereo image

$F_{1\_Z=\min} = F_1(X_0, Y_0, Z = Z\_\min)$

$F_{2\_z=\min} = F_2(X_0, Y_0, Z = Z\_\min)$

X_0, Y_0 are initial value of X and Y

$Z\_\min$ is the minimum value of the fixed height information

$$row\_right\_start = G_1(X,Y,Z=\min)$$
$$col\_right\_start = G_2(X,Y,Z=\min) \qquad (3\text{-}9)$$

In the equation (3-8), X and Y are calculated using Iterative Least square method, and then we can find the starting point of right image with substitute X,Y in the equation (3-9). Using the same method, in right image the end point correspond to any point of left image can be calculated

$$F_{1\_Z=\max} + (\frac{\partial F_1}{\partial X})dX + (\frac{\partial F_1}{\partial Y})dY = row\_left$$
$$F_{2\_Z=\max} + (\frac{\partial F_2}{\partial X})dX + (\frac{\partial F_2}{\partial Y})dY = col\_left \qquad (3\text{-}10)$$

$$row\_right\_end = G_1(X,Y,Z=\max)$$
$$col\_right\_end = G_2(X,Y,Z=\max) \qquad (3\text{-}11)$$

Through equation (3-8) ~ (3-11), in right image, we can find the start point and end point corresponding to any one point of left image. It will be a straight line to connect these two points and this line will be epipolarity approximately. When matching, this line will be used.

3.4. Calculation 3D Points From Stereo Pair

In order to generate Digital Elevation Models (DEM) , a process to calculate World Coordinates X, Y, Z from matched stereo pair must be required.

In this section, we will consider the problem to calculate 3 D World Coordinates from matched stereo pair. In 3.3 section we mentioned about rewriting equation (2-2) to (3-7) using Taylor series theory. Now equation (3-7) is rewritten for stereo pair as following.

$$F_{1\_0} + (\frac{\partial F_1}{\partial X})dX + (\frac{\partial F_1}{\partial Y})dY + (\frac{\partial F_2}{\partial Z})dZ = r\_left$$
$$F_{2\_0} + (\frac{\partial F_2}{\partial X})dX + (\frac{\partial F_2}{\partial Y})dY + (\frac{\partial F_2}{\partial Z})dZ = c\_left$$
$$G_{1\_0} + (\frac{\partial G_1}{\partial X})dX + (\frac{\partial G_1}{\partial Y})dY + (\frac{\partial G_2}{\partial Z})dZ = r\_right$$
$$G_{2\_0} + (\frac{\partial G_2}{\partial X})dX + (\frac{\partial G_2}{\partial Y})dY + (\frac{\partial G_2}{\partial Z})dZ = c\_right$$

(3-12)

Where, if X_0, Y_0, Z_0 are initial value of World Coordinates X, Y, Z

$$F_{1\_0} = F_1(X_0, Y_0, Z_0)$$
$$F_{2\_0} = F_2(X_0, Y_0, Z_0)$$
$$G_{1\_0} = G_1(X_0, Y_0, Z_0)$$
$$G_{2\_0} = G_2(X_0, Y_0, Z_0)$$

Equation (3-12) can be rewritten to the following error equation briefly

$$\begin{bmatrix} \frac{\partial F_1}{\partial X} & \frac{\partial F_1}{\partial Y} & \frac{\partial F_1}{\partial Z} \\ \frac{\partial F_2}{\partial X} & \frac{\partial F_2}{\partial Y} & \frac{\partial F_2}{\partial Z} \\ \frac{\partial G_1}{\partial X} & \frac{\partial G_1}{\partial Y} & \frac{\partial G_1}{\partial Z} \\ \frac{\partial G_2}{\partial X} & \frac{\partial G_2}{\partial Y} & \frac{\partial G_2}{\partial Z} \end{bmatrix} \begin{bmatrix} dX \\ dY \\ dZ \end{bmatrix} = \begin{bmatrix} r\_left - F_{1\_0} \\ c\_left - F_{2\_0} \\ r\_right - G_{1\_0} \\ c\_right - G_{2\_0} \end{bmatrix}$$

$$\mathbf{A} \cdot \mathbf{Offset} = \mathbf{L}$$
$$\mathbf{Offset} = (\mathbf{A}^{\mathrm{T}} \cdot \mathbf{A})^{-1} \cdot \mathbf{L}$$

(3-13)

In Equation (3-13), we can solve the Offset vector using the iterative least square method and then World Coordinate X, Y, Z can be calculation.

4. RESULTS

4.1 Test Data

In this study, the panchromatic data of Nonsan area of KOMPSAT1 satellite from Space Imaging was used for approximation of Polynomial Camera and generation of DEM. Basic information about this data is listed table 1

	Left Image	Right Image
Ground pixel Size	6.6 m	6.6m
Sun Azimuth Angle	134.1528	128.1780
Sum Altitude Angle	60.0369	58.7360
Date and Time of Acquisition	2000/05/01 02:07:07.869	2000/04/28 01:49:24.227
Standard Ellipsoid	WGS 84	WGS 84
Image Pixel size (pixel)	Row:2797 Column:2592	Row:2797 Column:2592
Azimuth	685km	685km

Table 1 Basic information of KOMPSAT1 scene(Nonsan)

4.2 Camera Modeling Result

To estimate each Polynomial Camera Model, we calcu lated root mean square errors (RMSEs) of GCPs and ch-eck points (CPs).The unit is pixel and the number of GCPs is 21 and CPs 10.

	Row (GCP)	Col (GCP)	Row (CP)	Col (CP)
X:1 Y:1 Z:1	3.379162	2.290543	2.723790	3.130205
X:1 Y:2 Z:1	1.781192	0.737140	2.941706	1.8117892
X:1 Y:2 Z:2	1.772667	0.730612	2.921159	1.749009
X:2 Y:1 Z:1	1.253481	0.837268	1.264619	1.547359
X:2 Y:2 Z:1	1.209972	0.590887	1.484051	1.385423
X:2 Y:2 Z:2	1.132958	0.561193	1.212340	1.540187
X:3 Y:3 Z:3	0.361745	0.271739	4.524599	1.638546

Table 2 RMSE (unit: meter) of GCPs and Check Points (CPs)

4.3 Epipolariry Result

The result of epipolarity performance is displayed in the figure 1. We did experiment of epipolarity with 14 points of GCP and the result was represented by distance from approximated epipolar line to real point. The unit is pixel

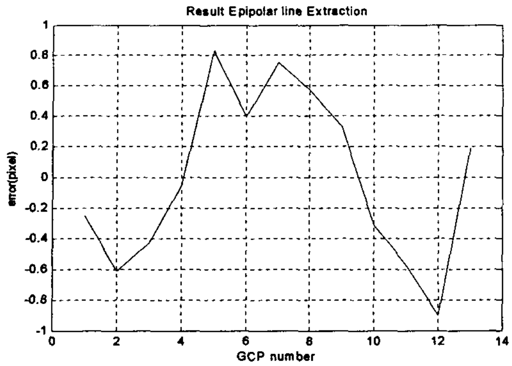

figure 1. The result of epipolarity
(RMSE =0.5372 pixel)

4.4 Result of Reconstruction 3D Points

The result of reconstruction 3D World Coordinates X, Y, Z corresponding to matched stereo pair is listed table3.

We calculated RMSE of GCPs and CPs and the unit is meter.

	GCP X	GCP Y	GCP Z	CP X	CP Y	CP Z
X:1 Y:1 Z:1	2.5147	2.0276	33.6031	3.5177	3.2215	41.0197
X:1 Y:2 Z:1	2.2055	1.9242	25.3493	3.4020	3.0971	31.7751
X:1 Y:2 Z:2	4.7863	3.3999	32.8543	4.8253	3.5115	36.7241
X:2 Y:1 Z:1	2.1968	1.8386	3.5410	2.3215	2.1357	5.3515
X:2 Y:2 Z:1	2.1729	1.8484	3.4990	2.2571	2.0917	4.7753
X:2 Y:2 Z:2	1.8143	1.7490	3.4919	2.0197	1.8871	4.5780
X:3 Y:3 Z:3	0.6262	0.1656	0.6481	0.8757	0.3572	14.3571

Table 3. Result of Reconstruction 3D World Coordinate
(unit: pixel)

5. CONCLUSIONS

In the section 4.2, we can examine the result modeling result. According to table 2, A good performance was resulted when the 2nd order of Polynomial Camera was selected. In theory when 3rd order will be selected, Polynomial Camera will have a good performance but the 3rd order Polynomial Camera is required at least more 20 points of GCPs. Table 3 was resulted with just 21 points of GCPs. So the performance of the 3rd order Polynomial Camera Model is worse than the 2nd order. If we use more GCPs, the performance of the 3rd order will be better than 2nd order. RMSE of CPs has a trend to decrease e with diminution of degrees.

In the section 4.3, there is a description about the performance of epipolarity. RMSE is 0.5372 pixel and we can talk that it is reasonable result.

We can examine the result of Reconstruction 3D World Coordinate X, Y, Z from matched stereo pair in the section 4.4. According to table 3, when the order of X, Y was selected over 2nd order, the result was good like a Modeling results. If the experiment is perform with more GCPs, the result of 3rd order Camera Model will be also better than table 3.

Finally, Polynomial Camera Model has the accuracy similar to RFM and is required more little GCPs than RFM. Polynomial Camera Model just use a half number of GCP required for generation DEM with RFM. So it can be said that Polynomial Camera compares efficient of RFM on GCPs.

In order to improve the accuracy of the DEM generation of the normalized correlation, the preceding process on the building boundary will be required. Otherwise the manual or semi-automated process is required for the DEM extraction

6. REFERENCES

1. *Richar I. Hartley, and Tushar Saxenam, The Cubic Rational Polynomial Camera Model, FOCUS Project Technical Report 1997*
2. *Hye-Jin Kim, Hyo-Sung Lee, Yong-Il Kim, A study on Rational Function Generation from IKONOS Satellite Image ,International Symposium on Remote Sensing, 2001. 10.*
3. *Won-Hee Lee, and Jae-Bin,LeeA Study on the Rational Functions Generation from IKONOS Satellite Image Extraction of Three-imensional Terrain Information from the IKONOS Stereo Pair, International Symposium on Remote Sensing, 2001. 10*
4. *Richard I.Harley, and Andrew Zisserman, Mutiple View Geometry In Computer Vision, Cambridge*

University Press, 2000.

5. Gupta, R, and Richard I. Harley, Linear pushbroom cameras, Pattern Analysis and Machine Intelligence, IEEE Transactions on , Volume: 19 Issue: 9 , Sept. 1997

6.Strang Gilbert, Linear Algebra and Its Applications 3rd Edtion, Harcourt Brace Jovanovich, Inc,2001

7.Hyung-deuk,Rim,A Study on Camera Modeling of KOMPSAT and DEM(Digital Elevation Model) Extraction Using KOMPSAT Images, Sogang university, 2000