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Digital Elevation Model Extraction Using KOMPSAT Images

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Abstract : The purpose of this paper is to extract DEM (Digital Elevation Model) using KOMPSAT images. DEM extraction consists of three parts. First part is the modeling of satellite position and attitude, second part is the matching of two images to find corresponding points of them and third part is to calculate the elevation of each point by using the result of the first and second part. The position and attitude modeling of satellite is processed by using GCPs. Area based matching method is used to find the corresponding points between the stereo satellite images. The elevation of each point is calculated using the exterior orientation information obtained from sensor modeling and the disparity from the stereo matching.

In experiment, the KOMPSAT images, 2592 × 2796 panchromatic images are used to extract DEM. The experiment result shows the DEM using KOMPSAT images.

Key Words : DEM extraction, KOMPSAT, Sensor Modeling, Stereo Matching.

1. Introduction

The techniques to produce DEM have been used in many fields along the rapid development of image acquiring techniques. It has been playing more important role in GIS and remote sensing fields. The method of acquiring DEM is classified to two schemes. The one is to acquire DEM from a map and the other is based on aerial vision techniques. The former provides a relatively accurate DEM, but needs on the manual work and requires long processing time. The latter has an disadvantage of low accuracy in DEM because of resolution. Nowadays, as the resolution increases, the DEM extraction method using satellite images is frequently adapted in many fields.

Fig. 1 shows the block diagram of the DEM extraction system using aerial vision technique.

The paper is organized as follows. Section 1 is introduction. The camera modeling procedure of the DEM extraction system is discussed in Section 2. In Section 3, the stereo matching method is presented. In Section 4, the method of height calculation using the exterior orientation of camera obtained from modeling and disparity from matching are discussed. A DEM extraction

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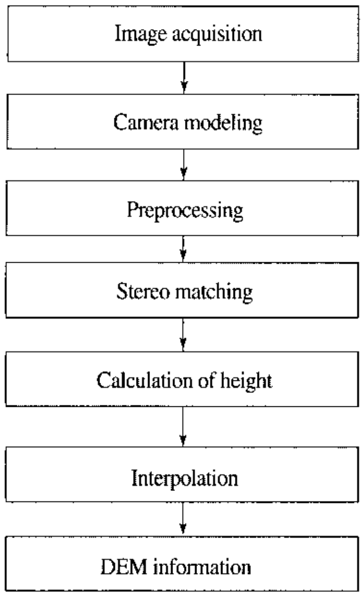


Fig. 1. Block diagram of the DEM extraction system.

method and simulation results are presented in Section 5. The paper ends in Section 6 with conclusions.

2. Camera Modeling with GCPs

Not all the status and position data of KOMPSAT satellite are given at each position but the data about 11~12 points are given by every 1 second interval. For estimating exterior orientation parameters of each image, the collinear condition is used. The collinear condition is that the vector from center of satellite to image plane is same as the vector from center of satellite to ground point corresponding image plane in eq.(1) and the equation of normalizing by Z factors is in eq. (2):

$$\begin{bmatrix} x \\ y \\ -f \end{bmatrix} = S M^T \begin{bmatrix} X - Xs \\ Y - Ys \\ Z - Zs \end{bmatrix} \quad (1)$$

$$\begin{aligned} Fx(\cdot)&=x+f\frac{a_{11}(X-X_s)+a_{12}(Y-Y_s)+a_{13}(Z-Z_s)}{a_{31}(X-X_s)+a_{32}(Y-Y_s)+a_{33}(Z-Z_s)}=0 \\ Fy(\cdot)&=y+f\frac{a_{21}(X-X_s)+a_{22}(Y-Y_s)+a_{23}(Z-Z_s)}{a_{31}(X-X_s)+a_{32}(Y-Y_s)+a_{33}(Z-Z_s)}=0. \end{aligned} \quad (2)$$

By using satellite's linear uniform motion during image aquisition period, exterior orientation parameters are approximated to function of time, linearized by Newton's 1st order approximation and transformed into matrix form as eq. (3):

$$V_1 + B_1 d_1 + B_2 d_2 = C_1. \quad (3)$$

Conformity-ellipse coordinate system which transformed from Bessel ellipse coordinate system is used in geodetic survey and map coordinate system in Korea and GRS 80(Geodetic Reference System 80) coordinate system is used for KOMPSAT coordinate system. The two coordinate systems are transformed into local space rectangular coordinate system. The Z axis used in local space rectangular coordinate system passes the origin point of corresponding area and go through the outer of ellipse, X axis is perpendicular to Z axis and decreased with longitude Y axis is perpendicular with X to Z axes and decreased with latitude.

The observing equation described by approximated value and observed value is as follow:

$$V_2 - d_1 = C_2,\ V_3 - d_2 = C_3. \quad (4)$$

The observing equation is derived as eq (5) from eq. (3) and eq. (4):

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} + \begin{bmatrix} B_1 & B_2 \\ -I & 0 \\ 0 & -I \end{bmatrix} \begin{bmatrix} d_1 \\ d_2 \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix}. \quad (5)$$

By simplified notation, eq. (6) is obtained

$$V + Bd = C. \qquad (6)$$

By applying least-squared method to eq. (6) and the square of residual is represented:

$$Q \sum_{i=1}^{m} (\frac{V_i}{\sigma_i})^2 = V^T WV. \qquad (7)$$

From eq. (6) and eq. (7),

$$Q = (C-Bd)^T W(C-Bd) = d^T B^T WBd - d^T B^T WC - C^T WBd + C^T WC. \qquad (8)$$

Applying partial differentiation about d then,

$$\frac{\vartheta Q}{\vartheta d} = 2B^T WBd - 2B^T WC \qquad (9)$$
$$\therefore (B^T WB)d = B^T WC.$$

By letting $N = B^T WB$, $k = B^T WC$, the result is simplified as eq. (10):

$$Nd = k. \qquad (10)$$

By ordering eq. (10) about differential vector d_1 of exterior orientation, eq. (11) is derived and by arranging about differential vector d_2 of GCP (Ground Control Point), eq. (12) is derived:

$$d_1 = (N_1 - N_2 N_3^{-1} N_2^T)^{-1} (C_1 - N_2 N_3^{-1} C_2) \quad (11)$$

$$d_2 = (N_2 + W_3)^{-1} (K_2 - W_3 C_3 - N_3^T d_1). \qquad (12)$$

d_1 and d_2 are offset vector to approach true values by linearizing collinear condition equation and offset vector used in this paper about all GCPs is derived as follows:

$$\begin{aligned} d_{2j} &= (N_{2j}+W_{3j})^{-1}(K_{2j}-W_{3j}C_{3j}-N_3^T d_1) \\ &= (N_{2j}+W_{3j})^{-1}(K_{2j}-W_{3j}C_{3j}) - \\ &\quad (N_{2j}+W_{3j})^{-1} N_{3j}^T d_1. \end{aligned} \qquad (13)$$

Because the physical meaning of d_1 and d_2 is the offset values to approach the true values of exterior orientation parameter and GCP, after finishing a series of calculation each GCP offset vector is iterated by adding estimated value and offset value. until all offset vector d_{2j} are approached to a small value which is negligible. The convergence test of modeling used in this paper is that if the normalized after during the summation of squared error with the number of test points as eq. (14) the value is converged:

$$\text{MSE} = \frac{\sum_{i=1}^{nc} R_i^2}{nc}. \qquad (14)$$

where

nc: test Point, R: error(residual)

3. Stereo Matching

The accuracy of the generated DEM is influenced by stereo matching procedure to find corresponding points from two stereo satellite images. Stereo matching is classified into two catagories of feature based and area based matching. Generally, area based matching is used to extract DEM from stereo images. Fig. 2 shows the block diagram of the conventional area based

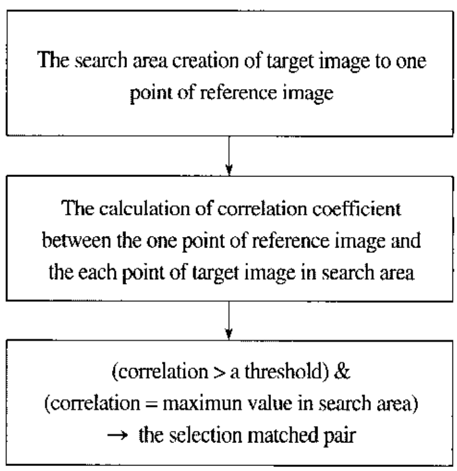


Fig. 2. Conventional area based algorithm.

matching.

The performance of area based matching depends on the selection of similarity measure to find corresponding points, the decision of window size and shape fitting acquisition images, etc..

4. Calculation of 3D information

In the case of near distance stereo images, the elevation of each point is calculated from simply proportion expression using the exterior orientation obtained from modeling and disparity from matching. Because the projection lines corresponding matched points of two images are exactly crossed at one point. But in the case of stereo satellite images, that of two images are not crossed at one point, due to the errors in influences of the orbit of satellite, the change of attitude and the rotation of the earth, etc. Therefore we select the nearest line of two lines, to decide the middle point of the line having the elevation of given corresponding point. Fig. 3 shows the 3D location decision by the nearest line of two lines.

5. Results

Fig. 4 shows test images acquired from KOMPSAT. The input images are portion pairs of 2592×2796 panchromatic digital KOMPSAT stereo image pair of Non-San in Korea. The camera modeling is performed using header file information and GCPs. The window size used for stereo matching is 19×19, and the threshold is 0.7 in this experiment.

Considering the relationship of satellite position and attitude, the orders of x, ϕ, ω, X_S, Y_S and Z_S to be 1, 1, 2, 1, 1, 2. The eq. (15) shows the result of camera modeling. Some GCP's are listed in Table 1 and test GCP's in Table 2.

Left Satellite

$$yaw = 9.23294618303921 + 0.00441858403767627t$$
$$roll = 19.779968369639 - 0.00150110721676283t$$
$$pitch = -5.47083159708492 + 0.0610917630113412t + 0.000597804816943571t^2$$

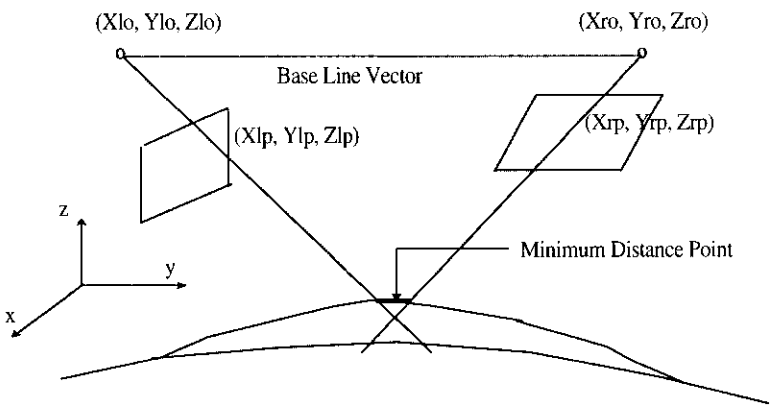


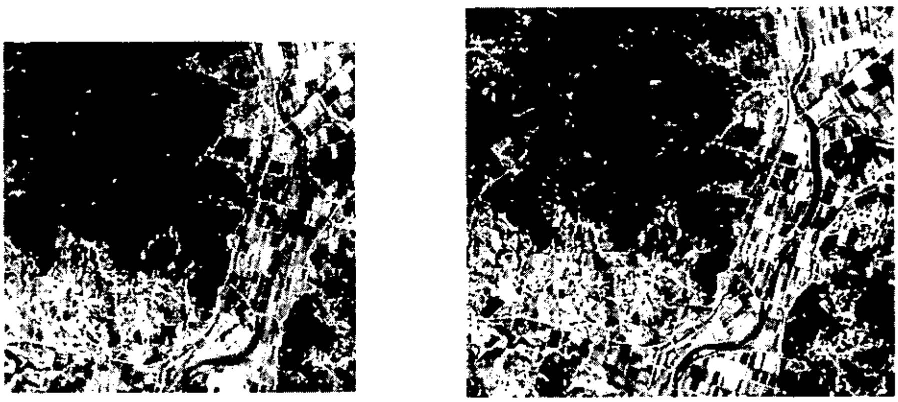
Fig. 3. 3D location decision by the nearest line of two lines.

Table 1. Ground Control Points(GCP).

Number	Latitude	Longitude	Height(m)	Left Image		Right Image	
				Line	Pixel	Line	Pixel
1	36° 19′ 27″ 696	127° 6′ 32″ 5	44.0183	1424.86	1490.14	1058.93	1706
2	36° 22′ 30″ 969	127° 6′ 7″ 889	47.8802	576	1562.92	214.11	1821.78
3	36° 19′ 48″ 207	127° 9′ 34″ 934	62.1868	1434.53	2097	1098.54	2364
4	36° 20′ 16″ 655	127° 8′ 14″ 399	55.6692	1260	1860.92	913	2115
5	36° 21′ 59″ 131	127° 7′ 13″ 497	109.1911	758.08	1750.92	405.07	2013.09

Table 2. Test Ground Control Points(GCP).

Number	Latitude	Longitude	Height(m)	Left Image		Right Image	
				Line	Pixel	Line	Pixel
16	36° 21′ 37″ 413	127° 8′ 50″ 709	59.2224	912.13	2043.93	573.23	2328.92
17	36° 20′ 40″ 626	127° 5′ 59″ 693	55.6908	1073.92	1446.92	705.89	1672.89
18	36° 15′ 35″ 560	127° 11′ 32″ 506	186.7803	2652.1	2275.8	2324	2495
19	36° 15′ 4″ 868	127° 6′ 59″ 787	18.5929	2640.17	1363.83	2268.13	1517.75
20	36° 15′ 36″ 940	127° 4′ 47″ 588	9.2825	2420.2	962.2	2028.33	1095



(a) Left Image (400 × 400) (b) Right Image (451 × 512)

Fig. 4. Non-San Image.

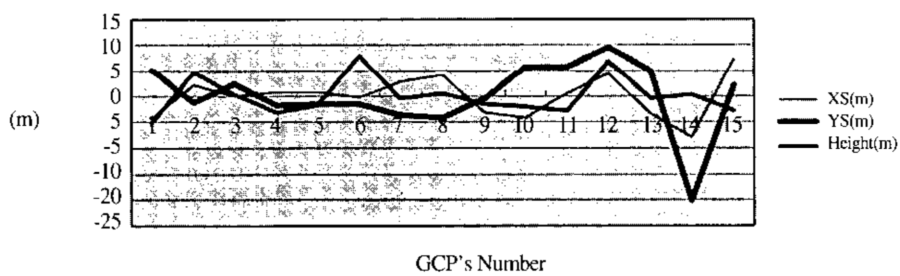


Fig. 5. X_S, Y_S, Z_S - Error of GCP.

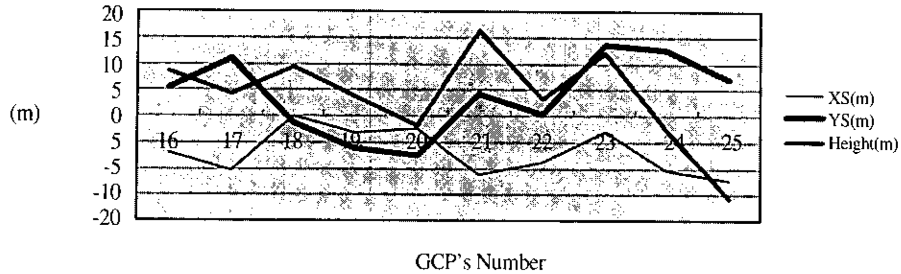


Fig. 6. X_S, Y_S, Z_S - Error of Test GCP.

Fig. 7. DEM Map.

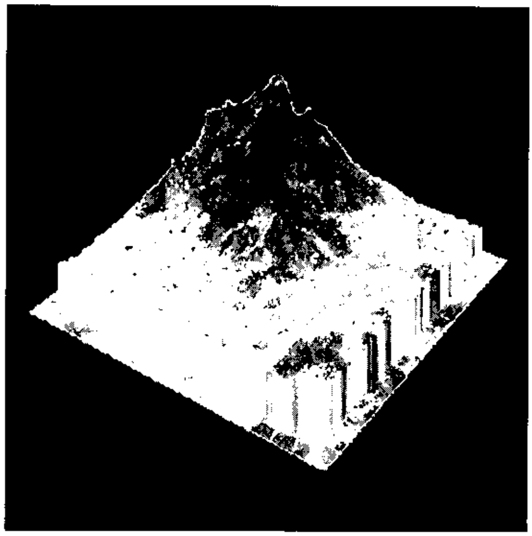


Fig. 8. 3D display of DEM.

$X_s = 241805.608142335 + 1345.6624381263t$
$Y_s = 63934.7843140943 - 7423.95469490569t$
$Z_s = 665260.56291953 + 38.4955155852265t + 18.443841186234t^2.$

Right Satellite

$\text{yaw} = 11.4550737534893 - 0.00642585922138551t$
$\text{roll} = -13.2096015409945 + 0.0129738942804131t$
$\text{pitch} = 0.469783111846987 + 0.044869270701925t + 0.000481703530532007t^2$
$X_s = -152772.514427057 + 1846.33466589096t$
$Y_s = -4886.52288847738 - 7172.47677307089t$
$Z_s = 662831.634470132 - 9.24085242875877t - 17.9233357115808t^2. \quad (15)$

Fig. 5 and Fig. 6 shows X_S, Y_S, Z_S – error of GCP and test GCP in the result. The RMSE of GCP converges into one pixel. Fig. 7 and Fig. 8 are the result of DEM map and 3Ddisply of DEM.

6. Conclusions

In this paper, we proposed a method on digital elevation model extraction using KOMPSAT images. The DEM extraction consists of three main parts such as camera modeling, stereo matching and calculation of height using exterior parameter and matched pair. We obtained the position and attitude modeling of satellite using GCP that was provided by Korea Aerospace Research Institute. The RMSE of GCP converged into one pixel, which is very accurate. We proceeded the area matching processing, the matching rate was 82.88%. The elevation of each point was calculated using the exterior orientation obtained from modeling and disparity from matching.

References

C. S. Ye, B. M. Jeon, and K. H. Lee, 1998, A Method on Digital Elevation Model Extraction Using Satellite Images, *Proceedings of International Symposium on Remote Sensing*, 342-348.

Jeong-Kee Kim, C. H. Park, and K. H. Lee, 1992, Automatic Digital Elevation Model Extraction Using SPOT Satellite Image, *Proceedings of IAPR Workshop on Machine Vision Applications*, 633-638.

T. S. Noh, 1997, *A study on Improvement of Stereo Matching Efficiency Using Gradient Correlation*, Sogang Univ., Korea

Poggio, V. Torre, and C. Koch, 1985, Computational Vision and Regularization Theory, *Nature*, 317: 314-319.