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Automatic Digital Elevation Model Extraction using SPOT Satellite Image

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Abstract

The purpose of this paper is to extract automatic DEM (Digital Elevation Model) using SPOT satellite stereo images. DEM extraction process consists of satellite modeling, image matching and elevation finding.

This paper presents the unified hierarchical matching technique and analyzes DEM error according to matching accuracy. The area-based matching is adopted for image matching and DEM is extracted by minimum distance point of two colinearity equation.

The matching strategy consists of three main sequential stages. The first stage classifies the area of the image of urban area, mountainous area and river. The second stage predicts image matched approximately by exploiting a priori knowledge about the geometry of a SPOT stereo model. The third stage is for multi-level matching. In this paper optimal search area from terrain slope is used to minimize aliasing and matching accuracy is improved than epipolar transform.

In the experimental test on the DEM, a set of test points is used as "ground truth." The points from the constructed DEM surface are checked against the corresponding test points. Difference of the two height at each DEM point is obtained. These differences are used to compute statistical values which are used as a measurement of DEM accuracy.

The input images used in this paper are 6000 by 6000 level 1A panchromatic digital SPOT image of Chung-chong Province, Korea. With 30 ground control points, experiments on SPOT level 1A full scene show that the planimetric RMS error is 7.10 m and the altimetric RMS error is 7.11 m for 38 test points. Extracted DEM experimental results show that RMS error amounts 12.5 m for 96 test points.

1. Introduction

A digital terrain model is an ordered array of numbers that represents the spatial distribution of terrain characteristics. In the most usual case, the spatial distribution is represented by an X-Y horizontal coordinate system and the recorded terrain characteristic is the terrain elevation, Z. Recent literatures have referred to these distribution as Digital Elevation Model (DEM) to distinguish them from other models which discribe different characteristics of terrain.

DEM is extracted using two digital SPOT images through three process. The first is to estimate status (ω, φ, κ) and position (X, Y, Z) of satellite when the satellite gets SPOT image(the modeling stage of satellite). The second is to match two images to find corresponding point of each image and the third is to calculate height by using disparity infomation taken in the second step, which is to match two images to find exterior orientation parameters and correspondig points.

In this paper we propose the method of making DEM automatically by using SPOT satellite images. The characteristics of SPOT image used are abstracted in chapter 2, the modeling procedure of SPOT satellite is represented in chapter 3 and the classification method of images is described in chapter 4. The matching procedure of each image is dealt in chapter 5. Finally we find height of each point and evaluate the result by using test points.

2. Characteristics of SPOT Satellite and SPOT Satellite Image [1,2]

SPOT (Satellite Probatoire d' Observation de la Terre) satellite is operating upon the sun synchronous orbit which is near polar orbit of height 832 Km with attached 2 HRV (High Resolution

Visiable) sensors consisted of 6000 CCD (Charge Coupled Device) arrays. The same area can be observed on different orbits by the satellite with $-27°$ to $27°$ and not only nadir viewing image but also off nadir viewing image can be obtained so as to make accurate DEM. One SPOT satellite image is consists of 6000 lines and one line is consists of 6000 pixels. In the wake of preprocessing condition, the produced SPOT image data is classified such as level 1A, 1B, 1AP, 2A, 2B and S. In this paper we use level 1A panchromatic image obtained on November 29th and 30th in 1987, which is Chung-cung Province, Korea.

3. Modeling of SPOT Satellite

Not all the status and position data of SPOT satellite are given at each position but the data about 9 points are given by every 1 minute interval. For estimating exterior orientation parameters of each image the collinear condition which states 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).

$$\begin{bmatrix} x \\ y \\ -f \end{bmatrix} = S\ M^T \begin{bmatrix} X-X_s \\ Y-Y_s \\ Z-Z_s \end{bmatrix} \quad (1)$$

$$F_x(\cdot) = x + f\frac{a_{11}(X-X_s)+a_{12}(Y-Y_s)+a_{13}(Z-Z_s)}{a_{31}(X-X_s)+a_{32}(Y-Y_s)+a_{33}(Z-Z_s)} = 0$$

$$F_y(\cdot) = y + f\frac{a_{21}(X-X_s)+a_{22}(Y-Y_s)+a_{23}(Z-Z_s)}{a_{31}(X-X_s)+a_{32}(Y-Y_s)+a_{33}(Z-Z_s)} = 0 \quad (2)$$

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 tramsformed 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 SPOT coordinate system. The two coordinate systems are transformed into local space ractangular coordinate system which is contacted with plane. The Z axis used in local space rectangular coordinate system passes the origin point of corresponding area and gose through the outer of gllipse, X axis is perpendicular with Z axis and direction which is decreasing longitudethe and Y axis is perpendicular with X and Z axis and direction which is decreasing latitude [3,4].

The observing equation described by approximated value and observed value is as follows.

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

By considering both two equations (3) and (4), the observing equation is derived as eq. (5).

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

By simplified notation, eq. (6) is obtained.

$$V + Bd = C \quad (6)$$

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

$$Q = \sum_{i=1}^{m}\left(\frac{v_i}{\sigma_i}\right)^2 = V^T W V \quad (7)$$

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

$$Q = (C - Bd)^T W (C - Bd)$$
$$= d^T B^T W B d - d^T B^T W C - C^T W B d + C^T W C \quad (8)$$

Applying partial differentiation about d then,

$$\frac{\partial Q}{\partial d} = 2\ B^T W B\ d - 2\ B^T W C \quad (9)$$

$$\therefore\ (B^T W B) d = B^T W C$$

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

$$Nd = k \quad (10)$$

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.

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

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

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

$$d_{2j} = (N_{2j} + W_{3j})^{-1} (K_{2j} - W_{3j} C_{3j} - N_{3j}^T d_1)$$
$$= (N_{2j} + W_{3j})^{-1} (K_{2j} - W_{3j} C_{3j}) - (N_{2j} + W_{3j})^{-1} N_{3j}^T d_1 \quad (13)$$

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 approximated to a small value which is negligible. The convergence test of modeling used in this paper is that if the normalized root mean square error (***RMSE***) less than threshold, after during the summation of squared error with the number of test points as eq.(14) the value is converged.

$$\text{where } MSE = \frac{\sum_{i=1}^{nc} R_i^2}{nc} \tag{14}$$

nc : test point, R : error (residual)

4. Clustering

We need to preprocess the images before starting to the matching process. The DEM of river and lake is actually dependent on the height of the surface of the water which changes every time when the satellite image taken and we have a problem of matching in this area. Because the change of configuration in mountainous areas is different from that of rice fields and urban areas, they needs matching adaptively.

So we need preprocessing step which classifies satellite area into mountain, urban areas, river and lake areas.

4.1 Conventional Clustering Algorithm

There are three main conventional clustering algorithms. First is to find edges of objects such as neighboring pixels, lines, isolated points and so on by using discontiunity of pixels, second is to get areas with same stastistical property by using similarity of pixels and third is to grow areas with same statistical property by comparing neighboring pixels (region growing, region splitting and merging, relaxation) [5].

The other methods are algorithms using histogram entropy represented by Kapur et al., preserving the moment of original image and image-regioned image proposed by Tsai et al., using statistical property of object and background which depend on the image proposed by Kittler et al..

Clustering algorithm of K-means algorithm, ISODATA algorithm and so on which minimize squared error and graph-theoretic clustering algorithm is MSTCLUS algorithm.

Conventional clustering methods applied to the images synthesized in lab. area have good performance but for the actual images such as satellite image, they may not have good performance.

4.2 Suggested Clustering Method

If N(x, y) < T1

$$MACU(x,y) = \begin{cases} -acu & \text{if } acu < 0 \\ 0 & otherwise \end{cases}$$

here, acu = −max{N(x, y) * wi}

T1 = the peak value of histogram

If DACU > T2

DACU = Dki   ki ∈ {1, 2, 3, 4}

here, N(x, y) * wk0 = max{N(x, y) * wi}

T1 * 0.7 < T2 < T1

otherwise DACU = 0

otherwise N(x, y) = 0

Setting sampled area with mountainous areas, urban areas, cities and rivers from original image, we find the statistical characteristics of these areas. For clustering, four 3 × 3 windows with four-direction component vector are used. From the gray levels of image, peak value is used as threshold value and the magnitude MACU(x, y) and direction DACU(x, y) of each pixel are found from the result of convolution value of each image. Considering the magnitude and direction, the pixels which are over each threshold value are remainded and so we can extract linear feature with one pixel width. Removing the noise of linear feature, the overall image with linear feature only is composed of some images with closed loops [6]. According to these steps, the image with small groups is made. Comparing the statistical characteristic of sub-images with small group with that of sampled area, the sub-images are classified as a group with maximum similarity value. If similarity value is lower than threshold value, classification is reserved and overall image is processed to classify. After ending these process, some areas which are not grouped are approximated to neighboring groups and they are replaced by the largest neighboring group.

5. Matching

Feature-based matching and area-based matching are the methods to find each same point of stereo images. Feature-based matching is to match features and to interpolate areas with no features and area-based matching is to match all the points by considering neighboring pixels which need matching [7].

Area-based matching is the method to choose the most similar area by comparing neighboring pixels with the other image to find corresponding point.

The matching method that accuracy is below one pixel is proposed in recent studies. Using area-based algorithm, we perform adaptive area-based matching by considering the property of area.

5. 1 Image preprocessing

There are some image preprocessing such as edge extraction, histogram equalization, sharping, epipolar align transform, and so on. In case of feature-based matching, the preprosessing is performed to extract features and matching performance is improved. But in case of area-based matching, the changes of gray level due to preprocessing can make the matching accuracy to be lowered, because the matching is performed by correlation between the images with a pixel and neighboring pixels. In this paper two images are matched by only using epipolar line constraint without preprocessing.

Similarity measurement is the function describing the resemblence between two corresponding areas, which is one of major factors governing accuracy, and normalized correlation is used for similarity measurement in this study.

The problems are pointed out of using same rectangular windows when matching each point of two images in coventional studies. Mori, Kidode and Asada and Quan proposed image warping mathod which equates two images step by step by warping another image about one image to solve the problem due to applying same window.

We consider that the left and right images of stereo image pair are differently according to image taking circumstances so we propose window warping method which uses different window shape by using disparity map when the the warped windows is applied to left and right images. The window warping procedures are as follows.

Step 1 : Making relative disparity map by subtracting direction X parallax value about matching point(center point) from center point parallax value.

Step 2 : Translating original grid points (rectangular grid points) to X direction by amount of relative disparity at their own position.

Step 3 : Making Y direction relative disparity map like step 1.

Step 4 : Moving X direction warped grid points in step 2 to Y direction like step 2 by using relative disparity map in step 3. Moved grid points are those of warped window.

Mismatched points which are taken by area-based matching need eliminating. We decide whether a point is mismatched or not by the size of similarity measure value, which generates some problems. Choosing high threshold value, generally we may find true point but because of the decrease of matching probability, matching percentage will be lower. On the other hand, setting threshold value lower makes matching probability higher but mismatched points will be increased. It is very difficult to find optimal threshold value from these trade off relationships.

In this paper the method of removing mismatched points is represented by using charateristics of geographical feature. Linear interpolation of neighboring 8-connected pixel values is used to estimate the height of nonmatched point. The reducing method of mismatched point is as follows :

Step 1. Assumming a point with lower correlation coefficient as mismatched point.

Step 2. Splitting correspondance fields into each group to satisfy condition 1.

Step 3. The number, mean correlation coefficient and mean slope of each group are calcurated to establish and remove the candidate groups.

Step 4. Merging other groups.

6. Result and Discussion

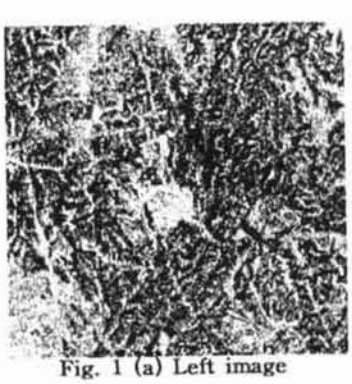

Fig. 1 (a) Left image

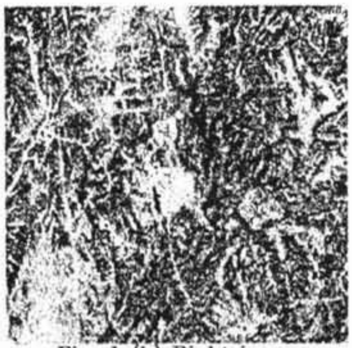

Fig. 1 (b) Right image

6.1 SPOT Satellite Modeling

Considering the relationship of satellite position and status, the orders of ω, φ, κ, X_s, Y_s and Z_s to be 2, 1, 1, 1 and 2 minimize errors. Some used GCP's are listed in table 1 and test points in table 2 and eq. (15) shows the result.

Table 1. Ground Control Points

latitude	longitude	height (m)	left image		right imag	
			line	pixel	line	pixel
36 ° 15′16″2	127 ° 18′06″5	80.96	4394	2197	4334	2352
36 ° 04′38″3	127 ° 40′26″4	149.91	5658	5913	5805	5408
36 ° 28′28″6	127 ° 40′26″9	212.04	1344	4811	1429	4647
36 ° 11′10″4	127 ° 02′30″2	5.36	5591	115	5417	629
36 ° 39′00″5	127 ° 11′05″5	80.79	299	89	121	815

Table 2. Test Points

latitude	longitude	height (m)	left image		right imag	
			line	pixel	line	pixel
36 ° 35′02″2	127 ° 41′18″0	43.00	3165	2862	3141	2950
36 ° 06′58″6	127 ° 66′08″3	185.00	5811	5807	5952	5309
36 ° 17′23″6	127 ° 06′19″1	7.00	5712	303	5549	773
36 ° 59′53″9	127 ° 22′75″8	60.00	825	586	675	1193
36 ° 57′12″7	127 ° 76′95″4	270.00	128	5338	244	5144

Left Satellite :

$\omega = -3.3748 * 10^{-5}\, t^2 - 0.10580\, t + 1.991,$

$\varphi = 0.12014\, t + 5.266,$

$\kappa = -0.00311\, t - 11.351$

$X_s = 3387.854\, t + 68452.918$

$Y_s = 7994.974\, t - 27211.392$

$Z_s = -8.8231\, t^2 - 226.5256\, t + 827744.152$

Right Satellite :

$\omega = 1.2107 * 10^{-5}\, t^2 - 0.10470\, t - 3.205$

$\varphi = 0.05265\, t - 26.042$

$\kappa = -0.00269\, t - 9.071$

$X_s = 1953.405\, t - 407378.570$

$Y_s = 8027.429\, t + 46836.839$

$$Z_s = -2.6791\, t^2 + 550.7611\, t + 816336.972 \quad (15)$$

Reducing points with error beyond threshold in 30 test points, 19 points are used at final stage and estimating control points used in modeling after satellite modeling, finally we conclude that plane-error is 4.07m and height-error is 3.97m. And using test points chosen from map plane-error is 7.11 m and height-error 7.10 m.

6.2 Clustering Experiment

To show that matching time is reduced with clustering satellite image and matching efficiency is increased by adaptive matching, we cluster satellite image by applying proposed method and conventional method, which are compared each other. Applied conventional methods are K-means algorithm and ISODATA algorithm and gray level is used as feature. The image used in this experiment is given in fig. 1.

Figure 2 show the results of K-means algorithm. These results show that mountain-areas are well classified than any other area because of slow change of gray level. When the number of classes is a few in urban areas, those areas are clssified as same area even though the change of gray level occurs. But if the number of classes increases, isolated points are increased and classification result is bad. In case of cities, the areas which belong to them are classified well but some areas with high intensity among river drifts, urban areas etc. As a whole, the problems are that how to merge images and how to process isolated points and edges.

Applying proposed clustering method on satellite image and extracting linear feature from it, the results are presented in fig. 3. In fig. 4 the result which shows the performance of linear feature which the noises are eliminated from is given. We make the closed loops using the linear feature with no noise terms, find statistical characteritics of pixels from each closed loop and classifies some areas as the neareast class. The classified result is in fig. 5. Reviewing the result which is retained by using proposed method, we conclude that the result which is classified by each small closed loop is superior to conventional clustering method.

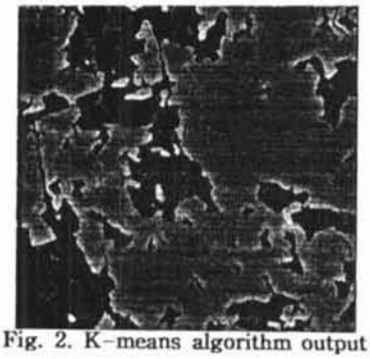

Fig. 2. K-means algorithm output

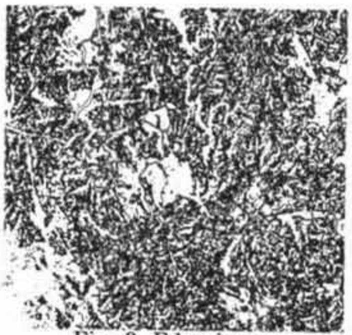

Fig. 3. Edge image

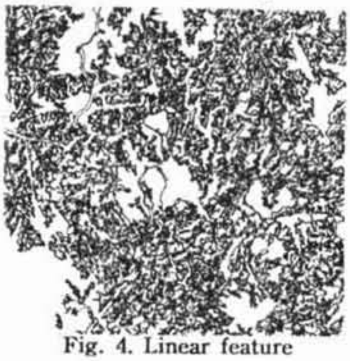

Fig. 4. Linear feature

Fig. 5. Clustering output.

6.3 Matching Experiment

On the basis of clustered area by proposed clustering method, the matching window sizes corresponding search areas are decided. Mountain areas are matched by the 0.2 sub-pixel and urban areas and cities the 0.5 sub-pixel. On the other hand, rivers or lakes are not matched but interpolated with each end value. The fig. 6 shows the matching result which decribes height.

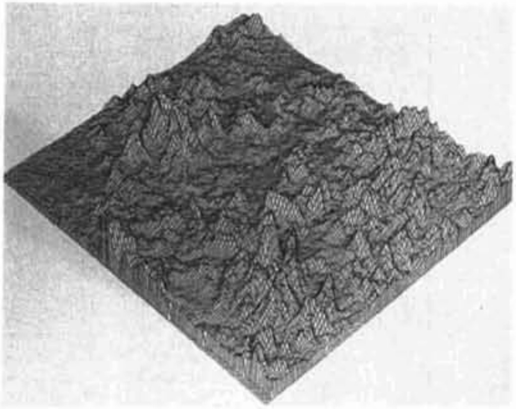

Fig. 6. DEM

7. Conclusion

In this study we proposed linear feature-based classification method to construct DEM automatically by using SPOT satellite digital image and matched each classified area adaptly by proposed way and saved DEM construction time also. And optimal window size and search area for each area make overall matching accuracy constant. Extracted DEM experimental results show that RMS error amounts 12.5 m for 96 test points. Extracted DEM experimental results show that RMS error amounts 12.5 m for 96 test points.

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