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A Fast Digital Elevation Model Extraction Algorithm Using Gradient Correlation

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Gradient Correlation을 이용한 고속 수치지형표고 모델 추출 방법

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Abstract

The purpose of this paper is to extract fast DEM (Digital Elevation Model) using satellite 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 results of the first and second part. The position and attitude modeling of satellite is processed by using GCPs. A area based matching method is used to find corresponding points between the stereo satellite images. The elevation of each point is calculated using the exterior orientation parameters obtained from modeling and conjugate points from matching.

In the DEM generation system, matching procedure holds most of a processing time, therefore to reduce the time for matching, a new fast matching algorithm using gradient correlation and fast similarity measure calculation method is proposed.

In this paper, the SPOT satellite images, level 1A 6000×6000 panchromatic images are used to extract DEM. The experiment result shows the possibility of fast DEM extraction with the satellite images.

Keyword : DEM extraction, stereo matching, gradient correlation

요 약

본 논문에서는 위성 영상을 이용하여 고속으로 수치지형표고 모델을 추출하기 위한 방법을 제안한다. 수치지형표고 모델 추출 방법은 위성의 위치와 자세를 계산하는 카메라 모델링 과정, 스테레오 영상으로부터 동일점을 찾아내는 정합과정 그리고 외부 표정 요소와 정합쌍을 이용하여 고도 정보를 추출하는 고도 정보 계산 과정으로 크게 구분된다. 이 중 정합 과정은 대상 영상의 모든 영역에 대하여 수행되므로 계산량이 많고, 수치지형표고 모델 추출 과정의 대부분의 수행시간을 점유한다. 따라서 본 논문에서는 수치지형표고 모델 추출 과정 중 대부분의 수행시간을 차지하는 정합 기법의 속도 향상을 통하여 수치지형표고 모델 제작 시간을 단축 시킨다.

본 논문에서 제안한 정합 기법의 속도 향상 방법은 두 가지로 분류된다. 첫째는 일반적으로 많이 사용되는 유사함수인 정규상관계수(NCC: Normalized Cross Correlation)에 비해 계산량이 적은 고속 GC(Gradient Correlation)을 사용한다. 둘째는 동일점을 찾기 위하여 사용되는 정합 창틀을 계산할 때, 이전에 미리 계산된 값을 이용하여 계산량을 감소시킨다.

실험에 사용한 입력 영상은 6000×6000 크기의 충청 지역 level 1A SPOT위성 쌍의 일부분이다. 실험 결과 기존의 수치지형표고 모델 추출 방법과 유사한 성능을 보이며 수행시간이 단축되는 것을 확인하였다.

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 and 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(Kim 1992). The paper is organized as follows. The camera modeling procedure of the DEM extraction system is discussed in the next section. 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 fast DEM extraction method and simulation results are presented in section 5, 6. The paper ends in the section with conclusions and a discussion of scope for future work.

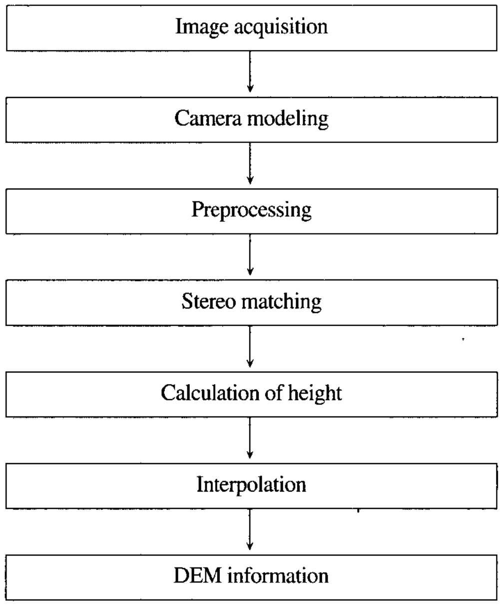


Fig. 1. The block diagram of the DEM extraction system

2. Camera Modeling with GCPs

The position and attitude modeling of satellite is processed using GCPs. To approximate the position and attitude of satellite, the collinearity condition equation is used. The epipolar constraint is that the vector from the center of satellite to image correspond to the vector from the center of satellite to ground point equivalent to image point. The equation (1) is the epipolar constraint equation.

$$\begin{pmatrix} xp \\ yp \\ zp \end{pmatrix} = sM \begin{pmatrix} X_e - X_e \\ Y_e - Y_e \\ Z_e - Z_e \end{pmatrix} \quad \cdots\cdots (1)$$

Where

xp, yp, zp : image coordinates of ground control point to image coordinate axis

X_s, Y_s, Z_s : position of satellite to local space rectangular coordinate axis

X_e, Y_e, Z_e : ground coordinate of ground control point to local space rectangular coordinate axis

s : scale factor

$M=Rot(z, -x)Rot(y, -\phi)Rot(x, -\omega)$: the attitude rotation matrix of satellite to local rectangular coordinate axis

x, y, z : the position of satellite , x, ϕ, ω : the attitude of satellite

From the equation(1) the exterior orientation is approximated using least square method with GCPs.

3. Stereo Matching

A DEM accuracy is influenced by stereo matching procedure to find corresponding points from two stereo satellite images. Stereo matching are 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 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.

1) The selection of similarity measure

The area based matching results are very influenced by the distortion of image geometry and change of illumination and contrast, because of using the grey level of each pixel as it is. Therefore, a normalized cross correlation is used as similarity measure. because it is not sensitive

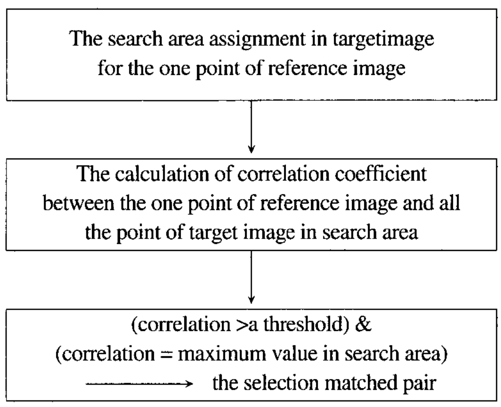


Fig. 2. The conventional area based algorithm

to that points. The equation(2) is used to calculate the normalized cross correlation.

$$Corr(i, j, m, n) = \frac{\frac{1}{N}\sum_{a=-w1/2}^{w1/2}\sum_{b=-w2/2}^{w2/2}(L[i+a][j+b]R[m+a][n+b]) - M(i, j)M(m, n)}{\sigma(i, j)\sigma(m, n)} \quad \cdots\cdots (2)$$

where w1, w2 : the size of window,

M : the average of grey level in window,

σ : the standard deviation of grey level in window.

2) The decision of window shape and size

The stereo images are acquired at a difference location and angle of camera. Therefore, the distortions of the stereo images are different and a fixed rectangular window cannot be used to determine a matching pair(Poggio et al, 1985). Two methods are used to solve this problem. The one is the window warping method which makes matching windows similarly. The other method is the image warping method which makes two images similarly. But this method needs a long processing time and the matched result of a previous stage.

The window size is decided by experiment. The larger window size is, the more accurate the matching result is, but the longer processing time is required. The smaller window size is, the shorter the processing time is required, but the probability of the mismatching is increased.

4. The calculation of 3D information

If the projection lines corresponding matched points of two images are exactly crossed at one point, the elevation of each point is calculated from simply proportion expression using the exterior orientation obtained from modeling and conjugate points from matching(Gonzalez, 1993). But in the case of stereo satellite images, the projection lines of two images are not crossed at one point due to the rotation of the earth, the change of satellite position and orbit and the incorrectness in the matched results and the exterior orientation parameters estimation, etc. Therefore the nearest line of two lines are selected, 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.

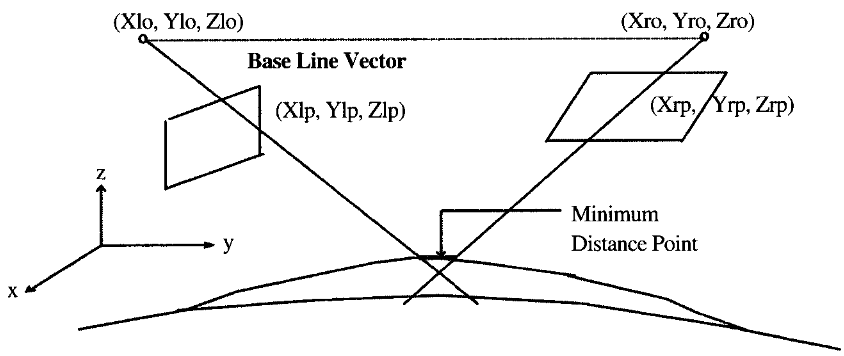


Fig. 3. The 3D location decision by the nearest line of two lines

5. A fast DEM extraction method

The processing time of a DEM extraction is much longer, because the matching procedure of two stereo satellite images to find corresponding point is processed for the entire point of image within the DEM extraction system. Therefore, a fast stereo matching algorithm is required.

A fast stereo matching algorithm can be implemented to use this:

- The reduction of the search window to find corresponding point.
- The selection of the similarity measure having a little number of operations.
- A fast similarity measure calculation method.

1) The reduction of the search window

Using the epipolar constraints, a 2-dimensional search region is reduced to 1-dimension search region. We determine the proper search interval from a previous matched pair, using the natural continuity constraints.

2) The selection of similarity measure having short processing time

In the area based matching, normalized cross correlation is generally used. But it has much number of operations. There are the sum of squared difference and the sum of absolute difference as the similarity measure having a little number of operation. But these decrease matching rate at complex terrain and weaken a noise. As another similarity measure, there is the gradient correlation using gradient vector. Gradient correlation is proposed by Crouzil(Crouzil, 1996). The equation (3) shows Crouzil's gradient correaltion.

$$C = \sum_{i=-n}^{n} \sum_{j=-m}^{m} (\| G^1_{i,j} \| + \| G^2_{i,j} \|),\ D = \sum_{i=-n}^{n} \sum_{j=-m}^{m} \| G^1_{i,j} - G^2_{i,j} \|$$
$$G^k_{i,j} = [a^k_{i,j}\ b^k_{i,j}]^T \equiv \left[\frac{\partial I_k(i_k+i, j_k+j)}{\partial x}\ \frac{\partial I_k(i_k+i, j_k+j)}{\partial y} \right]^T \qquad (3)$$
$$GC(i_1, j_1, i_2, j_2) = D/C$$

But Crouzil's gradient correlation has more number of operation than that of NCC. Therefore, in this paper, a modified gradient correlation used as similarity measure. The equation(4) represents a modified gradient correlation using the only y component of gradient vector(Noh, 1997).

$$C = \sum_{i=-n}^{n} \sum_{j=-m}^{m} (| b^1_{i,j} | + | b^2_{i,j} |),\ D = \sum_{i=-n}^{n} \sum_{j=-m}^{m} | b^1_{i,j} - b^2_{i,j} |$$
$$G^k_{i,j} = [a^k_{i,j}\ b^k_{i,j}]^T \equiv \left[\frac{\partial I_k(i_k+i, j_k+j)}{\partial x}\ \frac{\partial I_k(i_k+i, j_k+j)}{\partial y} \right]^T \qquad (4)$$
$$GC(i_1, j_1, i_2, j_2) = D/C$$

Table 1 shows the comparison of a number of operations with two window having N×M size.

Table 1. The comparison of a number of operations with two window having N×M size

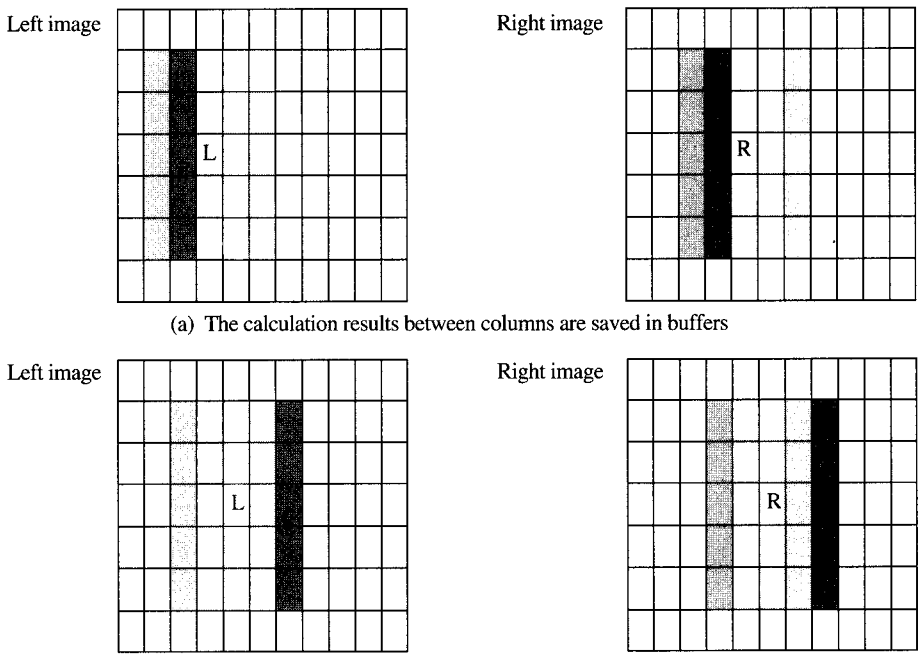
similarity measure	NCC	Crouzil' s GC	fast GC
+,-, absolute	4×N×M+2	6×N×M	5×N×M
×	2×N×M+6	6×N×M	0
%	4	0	0
square root	2	3×N×M	0

3) A fast similarity measure calculation method

A fast similarity measure calculation method is that a recursively calculated value save in buffer and the saved results are used for a next pixel' s matching, if necessary. In the case of a normalized cross correlation, it has the recursively calculated part as equation(5). So does gradient correlation.

$$\sum_{b=-w2/2}^{w2/2} (L[i+a][j+b]R[m+a][n+b]) \qquad (5)$$

Fig. 4. shows the calculation method of similarity measure



(a) The calculation results between columns are saved in buffers

(b) The saved results are used for a next pixel's matching

Fig. 4. The calculation method of similarity measure

To use a fast similarity measure calculation method, the distortion of images must be compensated. To reduce processing time, we used a kind of image warping method which compensate the distortion of images using affine coefficient obtained from GCPs.

6. Computer simulation

The input images are portion pairs of 6000 × 6000 level 1A panchromatic digital SPOT stereo image pair of Chung-Chong Province, Korea and the resolution is about 10m. The camera modeling is performed using header file information and GCPs. The window size is 19 × 19, and

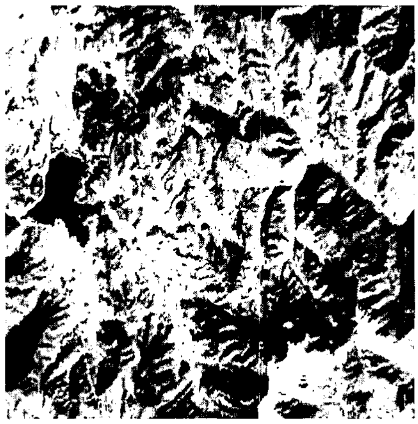
Table 2. The computer system used to experiment

System	Indigo Impact-2 workstation
CPU	R4400
Main memory	64Mbyte
Hard disk	4GByte SCSI hard disk
OS	IRIX 6.2

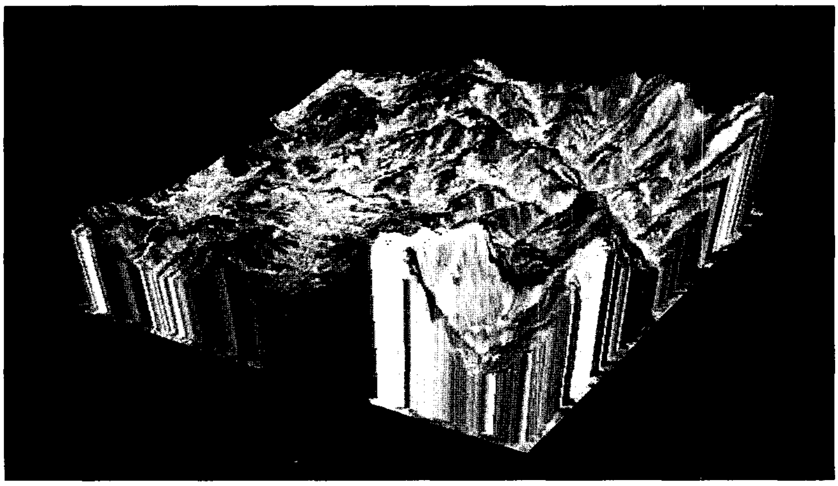
the threshold is 0.7 in this experiment. Table 2 shows the computer system used to experiment.

Fig. 5, 6. show an original input images pair acquired from SPOT satellite and DEM map as a result, respectively.

(a) Left image

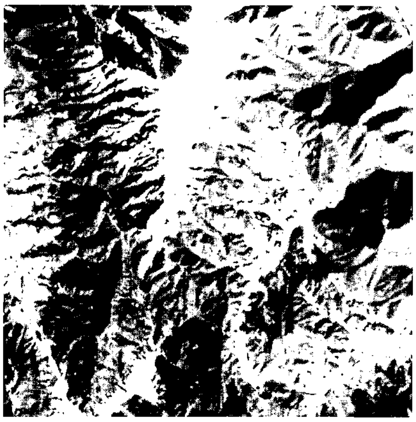


(b) Right image



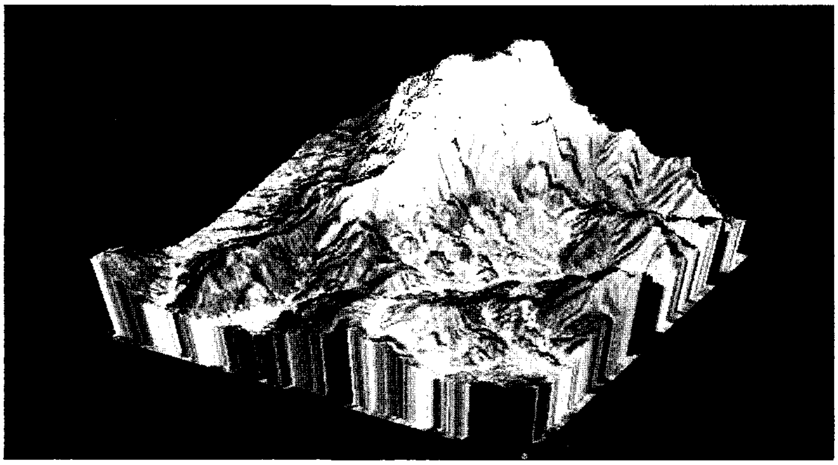
(c) DEM map

Fig. 5. Test image 1



(a) Left image

(b) Right image



(c) DEM map

Fig. 6. Test image 2

To compare a fast algorithm with a conventional algorithm used NCC without fast similarity measure calculation method, the input images of various sizes are tested. Table 2, 3, 4 show the matching results to each sizes, respectively. The experiment results show that the processing time of a fast algorithm is shorter than that of a conventional algorithm and the matched result is similar each other.

Table 3. The performance of each algorithm in 200 × 200 image

	Conventional	NCC	GC
Processing time	7min 19sec	2min 42sec	38sec
Average height	177.08m	178.43m	178.42m
Matched rate	98.8%	98.6%	98.8%

Table 4. The performance of each algorithm in 400 × 400 image

	Conventional	NCC	GC
Processing time	38min 26sec	12min 00sec	3min 20sec
Average height	244.76m	244.1m	243.83m
Matched rate	96.1%	96.0%	96.8%

Table 5. The performance of each algorithm in 800 × 800 image

	Conventional	NCC	GC
Processing time	3hour 14min 06sec	57min 44sec	25min 46sec
Average height	262.90m	263.44m	265.33m
Matched rate	95%	94.7%	95%

7. Conclusion

In this paper, a fast DEM extraction algorithm is proposed. The DEM extraction consists of three main parts such as camera modeling, stereo matching and calculation of height using exterior parameter and matched pair. Among the DEM extraction procedure, the stereo matching procedure spends a lot of times. To reduce processing time of DEM extraction, a fast gradient correlation and a fast similarity measure calculation method are used. Experiment results show that the processing time of a fast algorithm is shorter than that of a conventional algorithm and the matched result is similar each other. For the future work, Using a narrow region DEM, algorithm to form a large region DEM is to develop.

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