AUTOMATIC DEM DATA GENERATION AND CHANGE DETECTION
BY REGION MATCHING

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ABSTRACT:

The automatic DEM generation from stereo image pairs by computer aided matching is a fast and economic method. But the matching would fail when it is performed within the homogeneous intensity region, or in the regions which the land cover has changed when the satellite stereo pairs are taken with a long interval of time. This research tries to use the Conditional Rankorder Operator to smooth the intensity within the region first, then start Region Growing for Image Segmentation, the boundary of region can be extracted, and the shape can be described by ψ-s Curve, combine with other properties of region, such as the area, the position of gravity centre, etc., to form a Property List. The initial probability of region matching can be obtained by Minimum Cost Function with the weighting properties in the list. Then the matching probabilities are being adjusted by Relaxation Processes until the final conjugated region pairs are determined. The elevation of the region can be calculated with the conjugated region, and the Change Detection can be done by checking the mismatching regions and by comparing the intensity between the conjugated region after region matching.

Key Words : Region Matching, Segmentation, Region Growing, ψ-s Curve, Relaxation Process.

1. INTRODUCTION

The automatic DEM generation from digital stereo images by stereo matching is a fast and economic approach. But the low level intensity matching would fail when it is performed within a homogeneous intensity region, or in the regions in which the land cover has changed when the satellite stereo pairs are taken with a long interval of time. Therefore, the boundary of the homogeneous intensity region should be detected and extracted for high level feature matching. After region matching, the disparity between the conjugated region can be obtained for DEM generation. In the meantime, we confirm the regions of mismatching after region matching or by checking the intensity within the conjugated region, the change of land cover can be detected.

2. IMAGE SMOOTHING/ENHANCEMENT

For helping the region segmentation, we need to reduce noise and the small variation of grey value within the region on the one hand and enhance the edge features on the other hand. We review the linear operator, such as differential operators (e.g. Laplacian operator). There are some disadvantages, namely :
1. Blurring of the nearly homogenous background with / without noise interference.
2. The grey value and characteristics of linear features have been changed, it would be influenced by its background texture if we do not adjust the kernel of the operator according to the different backgrounds.

As a result of the inherent linear differential operator involved, a common limitation of linear operators is their amplification of high spatial frequency noise and artifacts. This situation can be improved by applying a low pass filter averaging mask based on regions of pixels first, but this might lead to smoothen the line/edge as well as the noise.

The alternative method can be that smoothing the relative homogenous area and then enhancing the edge/line. This would prevent the disadvantages previously mentioned. We can select the statistical (e.g. take mean) characteristics with non-linear operators (i.e. nonlinear combinations of pixels). For example, the Average Smoothing is a method by local clustering [Sijmons, 1986]. It is a straight forward way to remove noisy pixels and smooth a region by giving each point a new grey value which is the average of the original grey value in some neighbourhood of a point (e.g. 8 neighbourhood points) and with the point itself being included. This is a powerful method to smooth the region, remove the noise and detect the edge which is the boundary where the lower grey value abruptly changes to a high grey value (or vice versa). It will blur the thick lines, and suppress thin lines as well as isolated points. It also "clips" corners, after successive applications of the operator [Lo, 1985]. Because we like to retain the distinct linear features which are good for matching purposes, we can modify this method from linear into non linear smoothing by adding a condition and call it the Conditional Smoothing method. This method includes the condition that if a line/edge occurs in the sub-image during the convolution of the image, and the degree of distinction (i.e. the grey value difference between the

neighbouring points) of line/edge is above a certain threshold, the line/edge is preserved (i.e. not replaced by the average for smoothing).

Because smoothing with averages given in real values which have to be rounded off, therefor, it converges slowly in repeated applications of conditional smoothing, a better alternative is to take the median values of adjacent pixels instead of the average value. The Conditional Rankorder Operator has been developed according to this principle, which increases the rate of convergence [Mulder & Sijmons, 1984].

Based on the idea of conditional smoothing, this improved alternative method for line/edge feature enhancement is the following: If we use a 3x3 operator, the input subimage array is defined with linear index k:

$$\text{subimage [k]} \quad k = \begin{array}{|c|c|c|} \hline 1 & 2 & 3 \\ \hline 4 & 5 & 6 \\ \hline 7 & 8 & 9 \\ \hline \end{array}$$

subimage [5] is the central pixel grey value, then the 9 values (0-255) of subimage are sorted into array rank[r] with r = 1 the lowest value, r = 5 the median value and r = 9 the highest value in rank[r].

General algorithm:
do for all samples I, J
get 3x3 subimage at I, J and its 8 adjacent pixels
sort subimage [1...9] into rank [1...9]

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IF      ABS(subimage [5] - rank [r]) < threshold
THEN        subimage [5] = rank [r]
ELSE        subimage [5] = subimage [5]
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repeat the algorithm (the old output is the new input) until the result converges to stable output values. If we select r = 5 (i.e. the median value), it is the Conditional Median Rankorder Operator. This operator has the property of noise removal and it will converge segments (thick line also) to their median value (i. e. rank [5]) but still keeps every kind of line/edge features.

The condition on the difference between the central pixel value and the median value can be interpreted as an estimate of a Laplacian in a noisy environment. Estimation of a Laplacian in this way approximates that of the method of polynomial surface fitting for finding second order differences in a noisy subimage [Haralick, 1984].

The Conditional Rankorder Operator takes the neighbourhood lower value (e.g. use rank [2] instead of rank [5]) as the "relative" low pass filter to remove noise but shrink the high grey value and then take the neighbourhood higher value (e. g. rank [8]) with the same number of iterations to expand (restore) the high value to the proper size [Sijmons, 1986]. The conditional rankorder operator can smooth the region inside the edges and remove the noise, but the linear features are enhanced (their original intensity have been changed), for matching purpose, it is better that all linear features keep their original grey value without any change.

3. IMAGE SEGMENTATION AND BOUNDARY DETECTION

3.1 Image segmentation by region growing schemes

There are several image segmentation techniques, some of them are for general purpose and some are designed for specific classes of images. These techniques can be classed as : (a) Single linkage region growing schemes, (b) Hybrid linkage region growing schemes, (c) Centroid linkage region growing schemes (d) Split and merge schemes, (e) Measurement space guided spatial clustering, and (f) Spatial clustering schemes. (a) are the simplest and most prone to the unwanted region merge errors; (b) and (c) are better in this regard; (d) is not as subject to an unwanted region error, but it suffers large memory usage and excessively blocky region boundaries; (e) tends to avoid both the merge errors and blocky problems because of its primary reliance on measurement space, but the regions produced are not smoothly bounded, and they often have holes, giving the effect of salt and pepper noise. (f) may be better in this regard. (b) appear to offer the best compromise between having smooth boundaries and few unwanted region merges [Haralick & Shapiro,1985].

Before starting the Hybrid linkage region growing schemes, we scan the image pixel by pixel with a 3x3 patch, if the intensity of the pixels in the patch is the same, we use that patch as a "seed" for region growing. Starting with each seed, the neighbour pixels are checked and merged into a region if it is in a homogeneous area. Before region growing, all pixels are assigned by label 0. During the pixel merge, pixel i of region R wants to check pixel j whether it can be merged or not, the decision is made by the condition:

$$grey(i) - grey(j) < T, \quad T = K / \overline{\Delta g} \tag{1}$$

where K is a experimental value (e.g. K=30), $\overline{\Delta g}$ is the average gradient of grey value of 8 neighbour of pixel j, if the condition is met, pixel j is marked a label as a indication that this pixel belongs to region R. If some small region exist among big region or inside the big region, we merge this small region as it is not good for region matching.

3.2 Boundary detection

After segmentation, all pixels are labelled, we scan the whole image pixel by pixel with a 3x3 window. Within the window, if only one neighbourhood pixel (in horizontal direction) of central pixel has same label, this central pixel is the boundary pixel, or if only one neighbourhood pixel (in vertical direction) of central pixel has same label, this central pixel is the boundary pixel also. Then, we get the map of the region boundary.

4. REGION MATCHING BY RELAXATION PROCESS

4.1 Boundary description and comparison

Before region matching, the shape of region needs to quantify for comparison, the ψ-s curve is a good method for shape description [Baruch & Loew,1988]. According to the slop between two pixels on the boundary, the
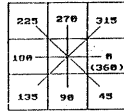
Chain Code can be assigned to it (Fig.1),

Fig.1 Chain code

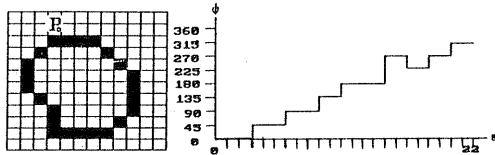then we transform the chain code and length to be ψ-s curve (Fig.2),

Fig.2 The shape description by ψ-s curve

then the shape of two regions can be compared by the curves, because the ψ-s curve has three characters:
(1) If the corresponding region pair has a different orientation, their ψ-s curve has a different shift in the vertical direction.
(2) If the corresponding region pair has a different starting point, their ψ-s curve has a different shift in the horizontal direction.
(3) If the corresponding region pair has a scale difference their ψ-s curve has a different length.
Therefore, during the shape comparison, we need to interpolate all the ψ-s curves into a uniform length, and extend the curve by repeating the ψ-s curve once; then during the comparison, we treat the ψ-s curve of left region as target window, and treat the extended ψ-s curve as search window, then compare/ search vertically and horizontally as we do in the matching procedure. The minimum difference between these two curves is the result of shape comparison. Because the resolution of the chain code is 45 degree only, we can smooth the curve with [0.1, 0.2, 0.4, 0.2, 0.1] operator for getting better resolution and better result of shape comparison.

4.2 Initial matching probability

The property of region can be used for region matching, such as the shape, the area, the grey value, the gravity centre etc.. For initial matching probability, the shape and area of regions in image 1 and image 2 are selected for Minimum Cost Function and the region difference $M(i,j)$ can be calculated :

$$M(i,j) = [shape1(i) - shape2(j)]^2 \qquad (2)$$
$$+ [Area1(i) - Area2(j)]^2$$

The similarity measure $S(i,j)$ is inversely proportional to $M(i,j)$ and is defined as:

$$S(i,j) = 1 / (1 + Cm * M(i,j)), \quad 0 < S(i,j) < 1 \qquad (3)$$

$$Cm = 2 / (Max(M(i,j)) + Min.(M(i,j))) \qquad (4)$$

where Cm is a scale factor, if image 1 (left image) has n regions, image 2 (right image) has m regions, then i= 1,2.....n and j=1,2......m. The smaller the value Cm is, the more sensitive the similarity measure becomes. The selection of Cm depends on the image quality. For

occlusion or imperfect segmentation or change of land use, some regions can not get the corresponding region in another image, a pseudo region called null region with index 0 is used, the similarity measure of i region of left image with its null region is define as:

$$S(i,0) = 1 - Max.(S(i,j)), \ i = 1,2....n, \ j = 1,2....m. \qquad (5)$$

The estimated matching probability $P(i,j)$ can be obtained by normalizing the similarity:

$$P(i,j) = S(i,j) / \sum_{k=0}^{n} S(i,k) , \ i = 1,2....n, \ j = 1,2....m. \qquad (6)$$

4.3 Compatibility of regions

If the matching of region is not independent on each other, we can use the compatibility, which is denoted as $C(i,j;h,k)$, to show the relationship of their dependency. If A match B denote as $A_i \epsilon B_j$ and their matching probability P_{ij} is strongly influenced by $A_h \epsilon B_k$, we say capability $C(i,j;h,k) > 1$. If $C(i,j;h,k) < 1$, it means $A_h \epsilon B_k$ has negative influence to $A_i \epsilon B_j$. If $C(i,j;h,k)=0$, it means there is irrelevance between $A_h \epsilon B_k$ and $A_i \epsilon B_j$.
For region matching, we can compare the interior angles of triangles which are constructed by three region gravity centers of two images each, as the compatibility [Lee & Lei, 1990], or we can simplify the angles into vectors (Fig.3) :
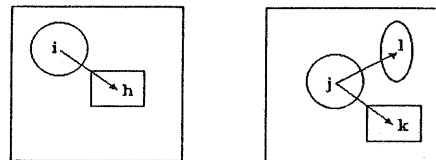
Right Image Regions   Left Image Regions

Fig.3 The vector of gravity centre of region

in Fig.3, if $A_i \epsilon B_j$, and the vector ih is the same as vector jk, then we say $C(i,j;h,k)=1$ and the P_{hk} would influence P_{ij} ; if the vectors (e.g. ih and jl) are completely different, we assign $C(i,j;h,l)=0$, it means $A_i \epsilon B_j$ has irrelevance with $A_h \epsilon B_l$, and P_{hl} has no influence to P_{ij}. If the matching probability P_{hk} is high and $C(i,j;h,k)$ is positive, we want to increase P_{ij}, since it is compatible with the high probability matching $A_h \epsilon B_k$. Similarly, if P_{hk} is high and $C(i,j;h,k)$ is negative or zero, we want to decrease P_{ij}, since it is incompatible with $A_h \epsilon B_k$ even it has high probability. A very simple way to define an influence to P_{ij} that has desired properties is to use the product $C(i,j;h,k) P_{hk}$.

4.4 Refinement of matching pairs

During the iteration for region matching refinement, the matching probability P_{ij} is adjusted by reinforce quantity $Q(i,j)$:

$$Q(i,j) = \sum (\sum C(i,j;h,k) * P(h,k)) \qquad (7)$$

the $Q(i,j)$ should be greater than 0 except when $C(i,j;h,k) =0$, the increment Q is used in refinement procedure:

$$P^{k+1}(i,j) = P^k(i,j) * (A + B * Q(i,j)) \qquad (8)$$
$$= A * P^k(i,j) + B * Q(i,j) * P^k(i,j), \quad j \neq 0$$

$$P^{k+1}(i,0) = P^k(i,0) \qquad (9)$$

where A $(0<A<1, e.g.\ A=0.3)$ is the decrease rate and B $(B>1,\ e.g.\ B=3)$ is the increase rate. When the reinforce quantity is small or 0, the A make the matching probability decrease. The selection of B is important because it may cause the matching process to progress normally or abnormally, if the B is too high, the all regions will play a major role with little significance in the matching process. That is, if a region pair is not a matched pair, it still has a high matching probability after convergence. On the contrary, if B is too low, the null region would influence the matching process significantly. That is, even when the contexture information supports a region pair, its matching probability will still decrease slowly, and finally a region will match with null region.

After each iteration for refinement, the matching probability needs to normalize:

$$P^k(i,j) = P^k(i,j) / \Sigma P^k(i,j), \qquad (10)$$

the $P(i,0)$ is not changed during the iteration, but it would change after normalization, and when $P^{k+1}(i,j) > P^k(i,j)$, the value of $P(i,0)$ will increase. The updating process is iterative until the match probability reaches a steady state, the match probability of the corresponding region would converge to 1, $P(i,0)$ would converge to 1, the remaining mismatching region would have matching probability converge to 0.

5. EXPERIMENTAL RESULT

5.1 Preprocessing

The resolution of digital stereos image pair is 1 meter, and we select a 200*200 pixels window from digitized stereo photo pair for experiment (Fig.4)

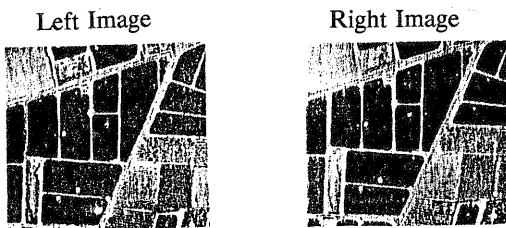Left Image   Right Image

Fig.4 The experimental image window pair

after image smoothing by conditional median rankorder filter, the seeds are generated as Fig.5.

Fig.5 The seed for region growing

After region growing, we can get the boundary of region as Fig.6.
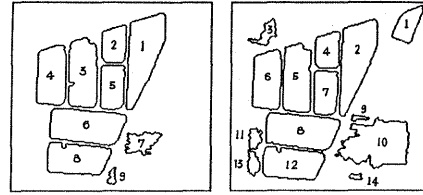

Fig.6 The boundary of region after region growing

5.2 Region matching by Relaxation procedure

a) The region difference is calculated from the shape and the area as Table 1:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	59	*1	106	73	44	47	78	29	75	111	116	53	110	91
2	23	118	77	*8	87	51	44	82	73	178	81	62	59	52
3	74	52	108	69	*14	29	60	38	94	124	112	41	91	86
4	56	69	125	52	29	*2	61	30	93	164	111	20	100	81
5	40	98	107	29	48	36	*1	65	70	208	96	59	75	62
6	81	40	135	70	27	32	45	*1	90	133	118	39	92	88
7	*35	111	58	*35	92	82	58	110	60	140	39	84	44	46
8	74	63	106	68	35	21	49	42	92	132	119	*2	89	99
9	38	120	53	48	86	71	67	96	38	198	60	85	32	*1

Right Image Regions / Left Image Regions

Table 1: The region difference

b) The initial matching probability which is calculated from region difference is as Table 2 (the figures in the table should be divided by 1000):

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	51	69	108	54	64	76	75	62	85	63	52	51	72	53	58
2	40	90	51	63	102	59	73	77	61	64	40	61	68	70	73
3	50	64	73	53	66	96	85	69	80	57	50	52	78	58	60
4	42	70	65	49	72	84	106	68	84	57	42	52	90	55	60
5	36	78	56	53	85	74	80	107	67	65	36	56	69	63	68
6	47	60	78	47	64	85	82	75	107	58	47	50	78	57	58
7	47	83	53	71	83	58	62	71	53	70	47	80	61	78	77
8	47	63	67	53	65	81	90	73	77	57	47	50	106	58	55
9	38	80	51	73	75	60	66	67	57	81	38	70	60	84	95

Right Image Regions / Left Image Regions

Table 2: The initial matching probability

c) The final matching probability by refinement procedure is as Table 3 (the figures in the table should be divided by 1000):

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	1000	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1000	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	1000	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	1000	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	1000	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	1000	0	0	0	0	0	0
7	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	0
9	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Right Image Regions / Left Image Regions

Table 3: The final matching probability

d) The result of region matching according to the final matching probability is as Table 4:

Left Image Regions	X	1	X	2	3	4	5	6	7	X	X	X	8	X	X	9
Right Image Regions	1	2	3	4	5	6	7	8	X	9	10	11	12	13	14	X

Table 4: The result of region matching

5.3 The Generation of height information

Before region matching, we obtain the exterior parameters of the camera by Absolute Orientation. Therefore, we can use these exterior parameters to get the conjugated epipolar lines, from the intersection of region boundary and conjugated epipolar lines, we can obtain the conjugated point pairs, then the space intersection is performed with the conjugated points, and terrain coordinate X, Y, Z of boundary can be obtained. For accuracy analysis, we measure and check the same points with WILD BC-3 manually, and the result of comparison is as in Table 5:

The difference of height(M)	No. of Points
0 - 1	50
1 - 2	7
2 - 3	3
3 -	0

Table 5: The accuracy of result in height

5.4 Change Detection

From table 4 we know which region has conjugated region, by checking the difference of grey value between these conjugated region pairs, the change of land cover can be detected. On the other hand, from table 4, we know which region can not get the corresponding region, it may be the new change of the land use.

6. CONCLUSIONS

1. The conditional median rankorder operator can smooth the grey value within the homogeneous area and does not change the grey value of boundary, it is good for threshold determination from the original image for later region growing.

2. The method of region growing is good only in homogeneous region, if we have a region with texture, the region can not grow and obtain the corrected boundary. This is the problem which we still need to solve.

3. For shape description and comparison, the ψ-s curve is a good approach.

4. Region matching by relaxation processing is a method of high reliability, the accuracy of matching can reach to one pixel.

5. A check of the difference in grey value of conjugated region and the mismatching region can offer useful information for change detection.

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