ON THE EXTRACTION OF ELEVATION INFORMATION FROM SPOT IMAGERY

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Abstract

This paper has analysed theoretically the problems at the key links in the procedure for elevation extraction using SPOT imagery by means of fully digital approach and the proposed methods which are necessary and flexible. The mathematical model of time-sequential exterior orientation elements must be taken according to the geometric characteristics of SPOT imagery. It is very important to chose the precise control points and the reasonable preliminary values of exterior orientation elements of central line and to calculate the equivalent focal length. The iterations for calculating the elements must be performed for the solutions of linear elements in one time and angular elements in other time, i.e. no solution for both at the same time, just as the case in aerophotogrammetry. New approaches should be taken for data organization, avoiding the loss of precision during the interpolation of elevation after automatic correlations. According to the satellite imaging characteristics, a strategy of multi-level matching are realized to improve the precision and the reliability, for which it is important to introduce the modified high accuracy least square matching algorithm. The results of the DEM generation using SPOT image windows in test area show us that they can reach the elevation accuracy of 10m when the image quality can be assured.

KEY WORDS: Data organization, Multi-level matching, Elevation extraction.

At the present time, there are two approaches to utilise the SPOT stereopairs to produce topo-graphis maps : analytical manner and digital manner. In this paper. We describe the elevation extraction from SPOT 1A data in a fully digital way. Theoretically and practically, the following four aspects which are key links for elevation information extraction shonld be taken into account: the solution of the exterior orientation elements, data organization for image matching, the strategy and the methods of image matching, the principle of DEM generation.

1. THE SOLUTION OF EXTERIOR ORIENTATION ELEMENTS

The solution of exterior orientation elemants is one of the key techniques in the procedure of extracting elevation information from SPOT images. As we know, each scanline of a SPOT image has its own perspective center and correspoding orientation elements. So the time-sequential exterior elementsmust be taken into account while seting up the collinearity equation.

Due to the effect of the earth curvature, the tangent plane coordinate system must be used. It is important to obtain the control points with sub-pixel accuracy for determination of image coordinates for those points Furthermore it must be noticed that the y coordinates of the image be transformated into that for "vertical photography" :

$$y_i=f(y_i'\cos\varphi+f\cdot\sin\varphi)/(y_i'\sin\varphi-f\cdot\cos\varphi) \quad (1)$$

where φ is the scanning angle, y_i is the column coordinate of the original image.

In order to solve the problem of correlation of angluar elements and linear elements, we have taken the alternative the iteration metthod for the two kinds of unknows.

The equivalent focal lenth should also be considered. and it can be computed using the parameter of flight height provided in SPOT CCT "Leader File".

The preliminary values of the exterior orientation elements and their variation rate parameters may affect the convergent speed of shading zones, in which the parallax can not be generated by matching algorithms or even by manual manner. So these areas in the image must be marked out before the matching processing, otherwise the reliable parallax grids can not be created. We have developed the quard- tree based seed region growing algorithm (Tao, 1992) to devide the image into different parts. The parts which belong to the dead-areas are marked with distinct signs and the parrallax values of the grid in these parts are interpolated by the neighbouring grid parallax values.

Based on the level 1 processing results, the two-dimensional matching is used, whereas the searching window is much small, namely, 7 pixels in line direction and 3 pixels in column direction. The most conjugate points are matched well in this sarching range. some points which are out of this range will be correctly determined by level 3 matching processing. In level 2 matching procedure, the multi-criterion matching method (Lin, 1988) and smoothing technique based processing are applied for improving the matching reliability. It takes about 90 seconds to generate the parallax grids of image with size 512×512 in this procedure.

3.3 level 3 image matching

In order to extract the elevation information more precisely, the sub-pixel points matching algorithm must be applied. Least squares matching algorithm (Ackermann, 1983) was used widely in the field of photognmmatry since it can provide very high accuracy (less than 0.1 pixel). however, there are two weak points of LSM that cause a limitation in application: time consumption and small pull-in range .

In fact, LSM can be treated as a adjustment system with additional parameters. From the additional parameters adjustment theory and our experiment results, we conclude that the main reasons of the above weakness are caused by the parameters selection in the LSM. Generally, eight transformation parameters (six for geometric and two for radiometric) for LSM are likely to be used. Theoretically speaking, the eight parameters are complete to compensate for the radiometric and geometric difference between the two correlation windows. In reality, however, in the case of small windows, the number of transformation parameters may be so sufficiently large that the correlation among the parameters occur to be put into effect. As a result, the model errors will be enhanced and the computation will become more time -consuming.

We have developed two modified LSM algorithm: SLSM and PDFM. The former one is the simplified LSM model for which only the four of eight parameters are taken into use. The four parameters (ho, hi, dx, dy) which determine the parallax values directly can be called main parameters in this case. The other four parameters can be considered to be supplement parameters which compensate for the rotation transformation. SLSM may be written as:

$$V_1 = h_0 + h_1 G_s(x, y) - G_m(x, y) \qquad (2)$$
$$V_2 = G_s(x+dx, y+dy) - G_m(x, y) \qquad (3)$$

where the unknows can be successively approached by alternating the use of the above formula (2) and (3).

For the purpose of improving the accuracy of the main parameters and reducing the model errors, we proposed a parameters dynamic filtering technique based LSM algorithm (PDFM). At first, the eight parameters are incorporated in adjustment while the conjugate points matching are active. After each time of the iteration , the parameters dynamic filtering is carried out by the t - hypothesis test. The statistical hypothesis is decsibed as followings :

$$t_i = a_i / \sigma \cdot \mathrm{SQRT}(\sigma_i)$$
$$\sigma = \mathrm{SQRT}(\sum (\Delta G)^2 / n-r)$$
$$\Delta G = G_s - G_m \qquad (4)$$

where a_i is the supplement parametar which has been used in the adjustment, and i denotes the ith supplement parameter. We take the significance level as the threshold for filtering the parameters. From the viewpoint of conservative -ness, α=10% is chosen and thus $t_{\alpha/2}$ is 1.65. After each iteration , once the t_i is less than $t_{\alpha/2}$, the parameter a_i is rejected from the succesive iteration of matching.

The comparative experiment results are shown in Tab.2 . SLSM has the advantages of the stability of accuracy, less consumption of running time and the large pull-in range as well (4-6 pixel). So SLSM is adopted to apply to level 3 matching procedure. In accordance with the criterion of speed, iteration times and accuracy, the PDFM is betler than LSM at all. The pull-in range of PDFM is enlarge also (about 2-3 pixel larger than 1~2 pixel of LSM). Therefore, the introduction of the parameters dynamic filtering technique is effective for improving the quality of LSM.

the solutions. So they must be estimated in proper way.

The solution of exterior orientation elements can be obtained with very high accuracy, if the above mentioned techniques are applied. It is shown from experiments that root mean squares (RMS) of control points is 0.5 pixel and RMS of check points is less than 1 pixel.

2. DATA ORGANIZATION FOR IMAGE MATCHING

After the solution of the exterior orientation elements and its variation rate of the left and right images, the terrain elevation can be calculated using the conjugate points coordinates after antomatic image matching. In order to generate the DEM data in regular grid base, the interpolation processing must be implemented to convert the elevation data of irregular grid to that of regular grid.

Considering the geometric characteristic of the SPOT data. We designed a new strategy for data organization before image matching procedure. We take one image (left or right) as a master image. The geometric rectification between the master image and the topographic map is performed by means of the polynomial transformation. The rectification result is illustrated in Tab.1, in which one can be seen that the planimetric errors are limited within 1 pixel. Approximately, if we create the regular grid on the master image, the grid can be taken as a orthophoto-grid. Based on this grid, the multilevel image matching and intersection are performed for each point of the grid and then the elevation data can be obtained, that is to say, the DEM has been generated. As can be seen, we have accquired DEM data in regular grid directly. The advantges of the above strategy are that the interpolation procedure can be avoided and the accuracy loss from the interpolation is also eliminanted.

3. MULTILEVEL IMAGE MATCHING

In Accordance with the geometric characteristics of SPOT image, the strategy of three level image matching is adopted as follows: the first level, image to image registration, the second level, image matching with accuracy of 1 pixel to generatse the coarse parallax grid, and the third level, high precision image matching with modified Least squares matching algorithm which can reach sub-pixel accuracy.

3.1 Level 1 image matching

In most image matching strategies for SPOT stereopairs, the 'epipolar' lines images are needed to be generated for restricting the correlation searching range. However. it is impossible to define exactly the epipolar geometry for SPOT, since a pair of SPOT images does not have corresponding pairs of straight epipolar lines. Dowman (Dowman, 1987) has put forward a method to settle this problem, but his method must need to know DEM data. Zhou (zhou, 1988) has proposed another way in which epipolar lines of SPOT stereopairs are arranged approximately using the ploynomial fitting technique. The main advantage of the Zhou's method is that it need not any orientation and terrain elevation information.

In this paper, the 'epipolar lines' images strategy which can be taken as a preprocessing procedure for matching has not been adopted. We take the approach of image to image registration as the first level procedure in multilevel matching. The approach is implemented by resampling the right or left image (the other is considered to be a master image), according to the ploynomial registration relation which is created by an amount of well-distributed corresponding control points selected by semiautomatic or automatic manner. It is shown from the test results that the ranges of parallax variation in all directions are restrricted by the registration approach, which is obviously different from the 'epipolar' processing approach since the latter confines only the parallax variation in verticle direction. So we called this step of registration processing as level 1 image matching.

Tab.1 illustrates the experiments resuts for two test areas. As can be seen that only a few control points are used and the parallax variation is well restricted, especially. in vertical direction, the maximum parallax is less than 3 pixels which is profitable to the successive matching processing. it should be mentioned that the block by block image registration processing should be implemented in the area where the relief is distinct.

3.2 Level 2 image matching

The purpose of this level is that the parallax grids with accuracy of 1 pixel should be generated as fast as possible. firstly, the image segmentation is carried out in the master (left or right) image. In the SPOT image, there are some areas, which we called matching dead-areas, such as clouds, snow, water and

4. INTERSECTION AND ANALYSIS OF EXPERIMENTS RESUILTS

It should be noted that the elevation of grid point is calculated by using the exterior orientation elements of the line in which the corresponding image point is located. According to the new data organization method, the following preparation must be made before intersection: the conjugat points coordinates are those of original image coordinates system, the exterior orientation elements of central line and its variation rate have been calcalated, the set of the grid points must form essentially orthophoto cases.

Tab. 3 illustrates the erperiment results of elevation information extraction from test area 1. It can be seen that RMS in three dimentional direction are all less than 10 m, which is calcalated in 23 check points.

5. CONCLUSION

It is feasible to utilise the SPOT stereopairs to extract the elevation information by means of fully digital processing manner. In the solution of exterior orientation elements, some techniques which can be applied to improve the accuracy of the solution should be taken into use. Multilevel image matching is implenented effectively and reliably, especialy, the modified LSM algorithms (SLSM&DPFM) are proved to be better than tranditional LSM algorithm in some extent. Intersection is carried out in regular grid to produce DEM directly which avoid the interpolation procedure and eliminate the accuracy loss in interpolation. Consequently, the accuracy of elevation extracted by fully digital processing manner can reach 10 m, as long as the the quality of image is assured.

Direction	RMS (m)
X	9.7
Y	8.5
Z	9.9

Table: 3 Accuracy Test for Intersection

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image pairs	size (pixel)	registration						rectification		
		control points			check points			control points		
		num.	σx	σy	num.	σx	σy	num.	σx	σy
test area 1	1024 ×1024	9	0.35 pixel	0.93 pixel	983	0.68 pixel	2.04 pixel			
test area 2	1310 ×1100	8	0.32 pixel	0.37 pixel	855	0.57 pixel	1.29 pixel	6	1.24 (m)	2.94 (m)

Table: 1 Accuracy of registration and rectification

window size (pixel)	LSM			SLSM			PDFM		
	iteration times	cpu-time (second)	accuracy (pixel)	iteration times	cpu-time (selond)	accuracy (pixel)	iteration times	cpu-time (second)	accuracy (pixel)
9×9	5.00	1.44	2.24	3.00	0.12	1.41	2.48	0.93	1.85
13×13	5.30	2.73	1.53	2.83	0.16	1.23	2.78	0.58	1.46
17×17	5.20	4.02	1.19	2.58	0.23	1.01	2.00	2.05	1.11
25×25	4.40	6.85	0.77	2.57	0.39	0.94	2.40	3.31	0.74
33×33	4.80	10.73	0.52	2.68	0.60	0.88	2.68	5.40	0.50

Table: 2 Comparison on iteration times, cpu-time and accuracy
(NOTE: the values in the table are the average results of 119 matching points)