MULTI-TEMPORAL DEM MATCHING METHOD WITHOUT CONTROL POINTS IN DEBRIS-FLOW AREA*

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ABSTRACT:

Detecting the volume change of loose deposit of rock debris accumulated and debris discharged is one of the methods to study debris flow. The volume can be resulted by overlapping multi-temporal DEM. As traditional method is based on control points, enough matching accuracy will be achieved only if the sufficient corresponding points are available to act as control points. DEM matching without control points provides new alternate approach to complete multi-temporal DEM matching when traditional method fails. Least z-difference (LZD), one of the precise algorithm, deal with two surface only contains random errors. However, multi-temporal DEM of debris flow contains not only the random error, but also non-random error caused by the debris discharged. The effect of E on observation equation is eliminated by giving different Belief Factor (BF) to height difference according to gradient. A test is performed on multi-temporal DEM of debris flow valley located in southwest of China. The experimental results show the RMSE of the method decrease from 4.27m to 1.03 m using BF.

1. INTRODUCTION

Debris flow is a kind of common natural hazards in mountain area. Debris flow contains a great number of soil, sand, scree and rock, erodes valley flanks and deposits in valley floor. Such mass relocation, which happens from initialization, development to occurrence of debris flow, is expressed as terrain change, such as the decrease of mountain height, deposition on the plain and erosion of valley floor. DEM, a digital description of real terrain surface, provides an important condition for terrain-change study. DEM is applied to many research works, such as natural hazard, water and soil loss and soil erosion. Altmaier and Kany apply the CORONA derived DSM to soil erosion, water and soil loss, and dynamics analysis of infrastructure change. They use the orthoimages to study of mapping change detection and generating thematic maps or land use classifications (Altmaier and Kany, 2002). Kääb uses the differences between multi-temporal DEMs to determine vertical terrain changes and uses multi-temporal orthoimages to calculate the horizontal movement (Kääb, 2002). In home, DEM has been used to the study of the topography character extraction and the drainage area classification (Fu and Chen 1993; Fu and Wang, 1994). Terrain change can be determined by overlapping multi-temporal DEM with the same spatial position, and the change refers to the volume of sediment deposited and debris discharged of debris flow. Using multi-temporal DEM to analysis the dynamic terrain change, it is needed to matching multi-temporal DEMs into a common coordinate system before processing the DEMs with grid structure.

The traditional method has enough accuracy if the control points are available. The control points are the pairs of corresponding points. However, finding the corresponding points is very difficult because of water and soil erosion and terrain reconstruction caused by debris-flow activity, especially for a long time span. The technique of DEM matching without control points provides a new approach to complete multi-temporal DEMs matching when the traditional method fails. The algorithms can be roughly divided into two parts: one is matching based on the feature, and other is whole matching. The latter does not require any prior-process, such as feature extraction and image segment. Least Z-difference (LZD) algorithm (Rosenholm and Torelegard, 1988), one of the main whole matching algorithms, proposed by Rosenholm in 1988 with a purpose of solving the absolute orientation of aerial images, is a algorithm with high matching accuracy and effective and uses widely. Karras and Petsa (Karras and Petsa, 1993) reported a robust LZD algorithm by adopting the date-snooping technique. It can detect deformation but its ability is very limit. Pilgrim (Pilgrim, 1996) replaced the least square by M-estimator and derived M-LZD algorithm, which can detect more percentage of deformation, and has more match accuracy. Furthermore, it has the potential to combine with other robust estimator.

There are two results to the difference among multi-temporal DEM. First, terrain surface changes owning to the sediment deposited and debris discharged of debris flow. Second, random error coming from the DEM generating process using the remote sensing images. Obviously, LZD, without considering the first aspect of the difference, is not an ideal method.. In order to overcome the shortcomings mentioned above, this paper proposed MBLZD algorithm by employing the belief factor (BF). Firstly, the terrain gradient should be calculated using the former temporal DEM. Secondly, according to the relationship between terrain gradient and the character of

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debris-flow activity, different belief factors are given. For details, the elevation change where terrain gradient is over 30°or from 10°to 15° creates which by the debris-flow form outflow is neglected by setting their BF is set to 0 firstly. Different BFs, from 0.1 to 1, are given to other slope value. Thus, the data error which causes by the debris-flow material outflow obviously reduces to the observational equation result influence and higher matching accuracy is expected reasonability.

2. CHARACTER AND MATHEMATIC MODEL OF TERRAIN CHANGE OF DEBRIS-FLOW VALLEY

2.1 Character of terrain change of debris-flow valley

The material of debris flow results from landslide, collapse of valley flanks and ground exfoliation. All of these are caused by the action of gravity .It directly relates to the terrain gradient. According to Ref. [9], the ground water and soil loss increases with the increase of the terrain gradient nonlinearly. The basic form of surface erosion is the exfoliation if the terrain gradient less than the critical value; otherwise, the main form becomes landslide and collapse.

So, the error of the two given temporal DEMs is the complex function of the original terrain gradient, the former temporal DEM, based on above physical model. The results of Lengshui valley of Ref. [10] show that the gradient of watershed and deposition area is less then 15° and the erosion of the watershed provides fine-grained material. Landslide parallel to rock layer is apt to occur in the 15° ~ 25° slope with sandstone roof.. The gully erosion is main form of surface erosion in the 25° ~ 35° slope, where connects the steep slope and gentle slope. In sequent landslide is tend to happen in the 35° ~ 45° slope, where is the retrograde slope. The incised valley and the retrograde slope of limestone are appeared in the area where the terrain gradient more than 45° and are the source of the collapse.

According to Refs.9/10 the surface erosion changes from exfoliation to collapse with the terrain gradient increasing. Although the same rules fit to the two study areas, the critical value of the erosion mode change is different owning to the different geologic condition.

2.2 Error Mathematic model of multi-temporal DEM of debris-flow valley

We suppose that e_1 and e_2 are random error resulting from the two temporal DEMs generating process respectively, and E is true change between two DEMs owning to debris flow. DZ contains not only e_1 and e_2, but also E. The e_1 and e_2 subject to normal distribution, but E doesn't. It is impossible to extract true error E in the sum of E and e1 and e2. Moreover, E changes greatly under different terrain gradient conditions. The matching accuracy of LZD based on least square decreased greatly due to above reason.

In order to eliminate the effect of E to the observation equation, we modify the LZD algorithm using BF and propose a new method, MBLZD. The new method gives different BF to dZ according to terrain gradient.
According to the above analysis, the belief factor (BF) of the point P(i, j) can be written as

$$B(P(i,j))$$

Where P(i,j) denotes the DEM gradient.

Then, the observation equation can be written as follows:

$$\min \sum B_i \left\| T(S_i) - M_j \right\|^2$$

or $$\min \frac{1}{N} \sum B_i \left\| T(S_i) - M_j \right\|^2$$

Where

2.3 Determination of Belief Factor (BF)

Puwai valley, locating in the northern part of Chengdu-Kunming railway, is a viscous debris-flow valley, which magnitude increases and often occurs in recent years. The area is of fully weathered Jurassic red region and with dry climate and large difference in temperature yearly. The debris flow has occurred for many times in history. It threatens the inhabitants nearby and railway transportation infrastructures.

Referencing the parameters of the similar researches on loess area and Lengshui valley, we give four sets of BF (See Tab.1).

Gradient	BF-1	BF-2	BF-3	BF-4
0°~5°	1.0	1.0	1.0	1.0
5°~10°	0.9	0.9	0.9	0.9
10°~15°	0.8	0.0	0.0	0.0
15°~20°	0.7	0.1	0.0	0.1
20°~25°	0.4	0.4	0.4	0.3
25°~30°	0.2	0.2	0.2	0.2
⩾30°	0.0	0.0	0.0	0.0

Tab. 1 Belief Factor (BF) indexes for difference gradient

The method to decide BF-1 is: the area where terrain gradient more than 30° is eroded greatly, and then dZ of such area could not be used and its BF is set to 0. About other area, the higher BF indexes are given respectively, from big to small, according to the gradient. Based on BF-1, we decide BF-2 according following measures. Firstly, The incised and deposit in the valley floor, where gradient is between 10° and 15°, cause great height changes without order, and then we set BF=0 to such area. Secondly, we give a very small BF (=0.1) to the area where gradient is 15°~20°, because sometimes the debris-flow may occurs in such area. Based on BF-2, we gives BF-3 by setting BF to 0 in the area where the terrain gradient is 15°~20°. In order to test the effect of BF, BF-4 is given by re-setting BF = 0.3 to the area where the terrain gradient is 20°~25° based on BF-2.

3. COMPARISON OF MATCHING ALGORITHMS AND ERROR TEST

In the experiments, both MBLZD, using BF, and M-LZD, without using BF, are employed to match the two DEMs, which are of 1957 and 1987 respectively. Considering the character of debris-flow activity, the big peak and ridge of the mountain are less affected. So, we choose 20 points in such area as check points. Their heights on 1987 DEM are using as the benchmark, and compare to the heights of their corresponding points on matched 1957 DEM. Then a statistical matching accuracy according to the height difference can be determined, and the results are listed in the Tab. 2.

According to the experimental results, the accuracy of MLZD and MBLZD-1 is lower than other three methods, and the accuracy of the latter three methods are close to each other;

Method	MLZD	MBLZD-1	MBLZD-2	MBLZD-3	MBLZD-4
Mean/m	0.944	11.080	0.006	0.016	0.005
Max/m	7.959	39.853	2.450	2.442	2.432
Min/m	0.402	0.032	0.046	0.015	0.051
Variance/m	4.272	19.049	1.029	1.039	1.030

Tab. 2 matching accuracy

The low accuracy of MLZD method because the ground changes greatly and exceeds its deformation-detecting ability; The reason of low accuracy of MBLZD-1 is: A big BF (=0.8) is give to dZ of gradient from 10° to 15°, where is debris-flow valley floor. At the same time, this part of ground occupies as high as 43.3% of the whole area. Then the real error (E) has a great effect on the observation equation;

The MBLZD-2, 3, 4 have high matching accuracy. It illustrates that these methods have eliminated the affection of E caused by debris flow. The slight difference of matching accuracy among them shows that the choosing of BF has some effect on the matching results.

4. CONCLUSION

During multi-temporal DEM of the debris flow valley matching processing, M-LZD, Robust LZD using M-estimator, couldn't avoid the bad effect of the true error (E) caused by sediment deposition and debris material discharging. The matching accuracy increases greatly after applying BF to height difference (dZ). Therefore, MB-LZD using BF is a more practical, effective method for multi-temporal DEM matching in the debris-flow area.

The slight change of matching result with difference BFs shows that choose of BF affects the matching accuracy.

The method proposed in this paper can be extended to other similar research fields. The generalized BF can be introduced to the application of the generalized height difference.

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