Anomaly Detection in Ground Object of Underground Nuclear Explosion Using TM Image

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***Abstract*—The comparison of multi-spectral images (so-called change detection) before and after the underground nuclear test can reduce search area for the on-site inspection and assist us in locating underground nuclear explosion (UNE). With TM images and multivariate alteration detection method, anomaly detection in ground object of a UNE was carried out by taking Pakistan UNE event as an example. In this paper a post-processing method was proposed based on the multivariate alteration detection. The correlation analysis between multivariate alteration detection variables and original multi-spectral images was studied as well as abnormal spectral characteristics of ground object associated with the UNE. The results indicated that the surface anomaly associated with the UNE partially corresponds to the observable phenomenon on the multi-spectral image and it is detectable through certain methods. The results also suggest that the multivariate alteration detection be in good generality on detecting anomaly in ground object of the UNE.**

***Index Terms*—Underground nuclear explosion, multivariate alteration detection, canonical correlation analysis, multi-spectral image.**

I. Introduction

Satellite remote sensing images play a critical role in monitoring of nuclear facilities, nuclear activities and nuclear explosions, and its importance becomes more and more significant. The underground nuclear explosion will result in the changes of geologic structure near the explosion center, generating cracks and even huge crater. The mountain surface near the explosion region may appear a large number of rising dusts and the ground surface temperature anomaly within certain scope around the explosion can be observed. With higher spectrum range the multi-spectral images can comprehensively record the various effects of ground surface changes after the UNE [1]. Utilizing the satellite images to find the abnormal information in ground object of a UNE and this is a study suitable for the multi-spectral image to assist in narrowing the search area in a large scope [2].

Canty M J [3] and Henderson J R [4] studied the important roles and potentials of satellite images in assistance searching and locating the UNE event theoretically and practically. Zhong Jiaqiang [5], Yu Yinfeng [6], Liao Mingsheng [7] et al theoretically explored the alteration detection method of multi-temporal and multi-spectral images. As the detection target of abnormal information in ground object of the UNE, its space geometry and distribution characteristics are unknown. Besides, the correlation between the channels of multi-spectral data is higher. These factors bring great difficulties in the anomaly detection of earth surface of UNE. In this paper we introduced one alteration detection method suitable for multi-spectral images of different time phases to detect the abnormal information in ground object of the UNE. This method named multivariate alteration detection selected linear combination pairs with minimum correlation of primitive variables and the difference value between them to constitute the components of alteration detection. On this basis, the correlation analysis between the multivariate alteration detection components and original images was implemented; the differences in ground object anomalies among the wavebands were studied; and the utilization potentiality of multi-spectral data on the abnormal information extraction in ground object of the UNE was explored.

II. METHODOLOGY

The methodology in this paper mainly includes the following steps, 1) geometric correction; 2) image registration; 3) relative radiometric correction; 4) alteration detection; and 5) post-processing the multivariate alteration detection.

A. Image Preprocessing

One premise of change detection is image registration. Here the registration between images was selected without ground control points. To avoid false detections, the registration accuracy must reach sub pixel level. In this paper the total RMS is lower than 0.4. In relative radiometric correction, the images before the explosion are taken as reference images. Adjust the image radiation characteristics after the explosion. Due to the sparse population and relatively single landscape in the UNE area, the darkest pixel method is used for relative radiometric correction.

B. Multivariate Alteration Detection

When analyzing the differences between the multi-band images of different time phases in the same area, , the gray value of the images is zero or the absolute value is relatively small for the area with no or little difference change; while for the area with great difference changes, its absolute value is relatively large [8-10]. Suppose the two multi-spectral images of different time phases both have K bands, $X=[X_1 \cdots X_K]^T$ and $Y=[Y_1 \cdots Y_K]^T$, and X and Y are of zero-mean, namely, $E\{X\}=E\{Y\}=0$. A simple difference conversion is noted as $X-Y=[X_1-Y_1, \cdots X_k-Y_k]$. Certain criteria should be found to measure the multi-band image alteration information. Respectively construct the linear variation of random vectors of the original two-time-phase images. Suppose $U=a^T X$ and $V=b^T Y$. The maximum variance of difference variables U-V is taken as measurement criteria and limit U and V both with unit variance. In this way, the multivariate alteration detection problem can be summarized into the mathematical problem below.

$$\begin{cases} Var(U-V)=Var(a^{T}X-b^{T}Y)=max \\ Var(U)=Var(V)=1 \end{cases} \quad (1)$$

Under the constraint condition of unit variance, we can obtain,

$$\begin{aligned} Var(U-V) &= Var(U)+Var(V)-2Cov(U,V) \\ &= 2(1-Cov(U,V) \end{aligned} \quad (2)$$

One premise of multivariate alteration detection method is that there is positive correlation between the linear combination variables U and V. In the way, U-V can be used to express the difference information. It can be seen from the above formula that if the variance of U-V reaches maximum, it is necessary to find the vectors *a* and *b* which make the correlation between U and V minimum and satisfy the constraint condition of unit variance. This indicates that the critical issue of alteration detection is to find out the linear combination pairs with minimum correlation of primitive variables and maximum variance of difference value between them which includes the maximum difference information. The image alteration of different time phases can be found through the analysis on each linear combination.

According to the canonical transformation theory, the above issue can be transformed into solving problem of canonical transformation. Carry out canonical transformation on two groups of random variables composed of two-time-phase multi-band images. Sequence them from small to large by canonical correlation coefficient and the difference of the corresponding canonical vector pairs is defined as MAD variable. Namely,

$$MAD=\begin{bmatrix} a_1^{\ T}X-b_1^{\ T}Y \\ \cdots \\ a_p^{\ T}X-b_p^{\ T}Y \end{bmatrix} \quad (3)$$

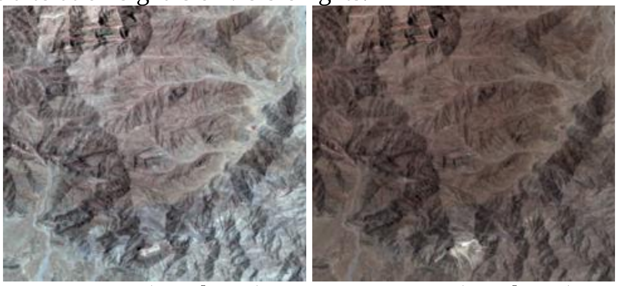
In the above formula, a_i and b_i are the nonzero vectors obtained from the canonical transformation for the linear structure of original vectors. U_i and V_i are the corresponding canonical vectors. It is obvious that the MAD component of i represents the difference of canonical vector of p+1-i [11,12].

III. CASE ANALYSIS

A. Data Selection

Landsat 5 launched in 1984 was selected as data source, witch owns higher spatial resolution and excellent spectrum capability besides is easy to acquire. For the detection of surface and vegetation change, it is completely acceptable with 30m spatial resolution and the data size is not huge. 16-day revisit period also satisfies the anomaly detection requirements. One region in Pakistan is selected as the experimental area and its original image is shown in Figure 1. The data acquisition time respectively was May 28, 1998 and June 13, 1998, with study area of 50 square kilometers. Expect TM6, the other bands are chosen for the study.

One UNE event was carried out on May 28 1998 in this area, with earthquake magnitude of mb 4.8. The reason for selecting this event lies in the obvious surface changes on the optical images, which may be caused by rock slide. In this case, the multi-spectral alteration detection results should similar to the alteration signals of visible lights.

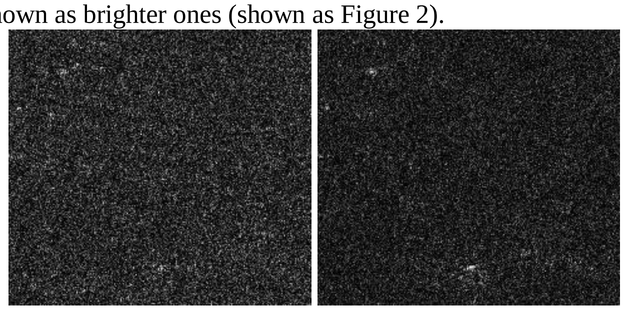


1998.05.28(Landsat 5) 1998.06.13(Landsat 5)

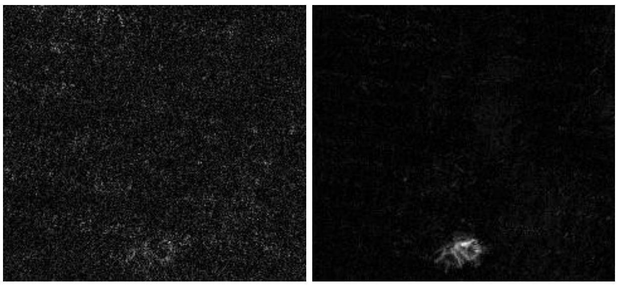
Fig. 1. Original image of a region in Pakistan

B. Processing and Analysis Procedures

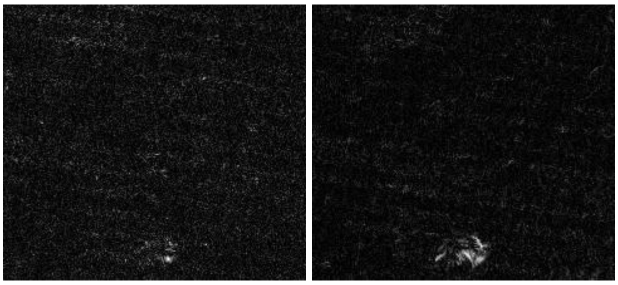
First of all, preprocess and centralized processing was carried out. Namely, we minuses the mean value of image from each pixel spectral vector in order to guarantee the zero mean vectors and obtain two images for canonical transformation. Then, we constructed linear combination on the original images after centralized processing and obtained the corresponding images of 6 pairs of canonical variables (figures are omitted). According the method in this paper, these 6 pairs of canonical variables were successively minused. Mirror processing was done and MAD variables were finally obtained. The result images reflect the difference between the two original images. The degree of closeness to zero between pixel values in MAD images reflects the difference between original images of different time phases in the same positions. The regions with great difference are too bright or too dark. To better the effect of visual analysis, we took the absolute values of MAD variables and the regions with great difference are shown as brighter ones (shown as Figure 2).



MAD1 variable image MAD2 variable image



MAD3 variable image MAD4 variable image



MAD5 variable image MAD6 variable image

Fig. 2. Corresponding images of MAD variables with absolute values

The corresponding canonical correlation coefficients, variance, variance contribution rate and accumulative variance contribution rate of MAD variables are shown in Table 1. Though the accumulative variance of former three MAD variables reaches 87.82%, it can be seen from Figure 2 that the former three variables contains too much noise and the alteration information almost is covered by the noise. The contribution rates of the latter three variables are small, but they fundamentally reflect the alteration information associated with the UNE, especially variable MAD 4 and variable MAD6.

TABLE I. VARIANCE DISTRIBUTION OF MAD VARIABLE

MAD variable	canonical correlation coefficients	variance	variance contribution rate %	accumulative variance contribution rate %
MAD1	0.0122	1.7789	43.97	43.97
MAD2	0.2122	1.0788	26.63	70.60
MAD3	0.4239	0.6978	17.22	87.82
MAD4	0.7636	0.2523	6.23	94.05
MAD5	0.8250	0.1834	4.53	98.58
MAD6	0.9409	0.0600	1.42	100

To further analyze the reflection spectrum anomaly of surface object before and after the nuclear explosion, the correlation coefficient between MAD variables and original variables were studied, shown as Table 2.

TABLE II. CORRELATION COEFFICIENT BETWEEN ORIGINAL VARIABLES AND MAD VARIABLES

correlation coefficient	MAD1	MAD2	MAD3	MAD4	MAD5	MAD6
0528TM1	-0.0447	-0.0453	0.0414	0.1988	0.0116	0.0723
0528TM2	0.0499	0.0055	0.0278	0.1935	0.0190	0.0763
0528TM3	-0.0055	0.0517	0.0344	0.1778	0.0248	0.0839
0528TM4	0.0101	0.0138	0.0191	0.1376	0.0636	0.0956
0528TM5	0.0013	0.0099	-0.0154	0.0901	-0.0209	0.1136
0528TM7	0.0135	0.0084	0.0657	0.0672	-0.0214	0.1158
0613TM1	0.0554	0.0625	-0.0336	-0.2022	-0.0017	-0.0697
0613TM2	-0.0333	0.0193	-0.0220	-0.1985	-0.0096	-0.0742
0613TM3	0.0144	-0.0238	-0.0268	-0.1849	-0.0159	-0.0818
0613TM4	0.0012	0.0089	-0.0187	-0.1492	-0.0523	-0.0937
0613TM5	0.0035	0.0122	0.0197	-0.0991	0.0236	-0.1116
0613TM7	-0.0077	0.0099	-0.0558	-0.0795	0.0256	-0.1141

The correlation coefficients between each MAD variable and each band of original images were shown as Table 2. It can be seen that the correlation between MAD1–MAD3 and original TM bands are weak and the correlation coefficients between variables are not significant. The correlation between MAD4 and TM1, TM2, TM3 and TM4 on May 28 and June 13 both are strong. There is a positive correlation between MAD4 and TM bands on May 28 and negative correlation between MAD4 and TM bands on June 13. These comprehensively reflect the reflectivity changes in ground object of TM1–4 before and after the nuclear explosion. The correlation between MAD5 and original bands is significant, which has a positive correlation with 0528TM1-4, a negative correlation with 0613TM1-4, a positive correlation with 0528TM5 and 0528TM7. However, the correlation between MAD5 and bands is so weak that it cannot reflect prominent alteration information. The correlation structure between MAD6 and bands is similar to that of MAD4. The difference is that the correlation between MAD6 and TM5 is strong as well as between MAD6 and TM7, which reflects the alteration information of middle-infrared bands of images before and after the nuclear explosion.

TABLE III. CANONICAL CORRELATION COEFFICIENT AND CANONICAL VARIABLES

NO.	Canonical correlation coefficient	canonical variables
1	0.9409	U1=-0.0116X1-0.0613X2-0.0433X3+0.0701X4+0.0346X5+0.0349X6 V1=-0.0218Y1-0.0712Y2-0.0257Y3+0.0690Y4+0.0318Y5+0.0359Y6
2	0.8250	U2=-0.0206X1-0.1099X2-0.0652X3+0.3226X4-0.0592X5-0.0304X6 V2=-0.0285Y1-0.0977Y2-0.0805Y3+0.3344Y4-0.0480Y5-0.0446Y6
3	0.7636	U3=0.0500X1+0.1305X2+0.0675X3-0.0882X4+0.0048X5-0.0623X6 V3=0.0252Y1+0.1298Y2+0.0826Y3-0.0810Y4-0.0023Y5-0.0543Y6
4	0.4239	U4=0.0569X1-0.0472X2+0.0862X3-0.0477X4-0.2474X5+0.3386X6 V4=-0.0572Y1-0.0404Y2+0.0546Y3-0.0208Y4-0.2566Y5+0.3452Y6
5	0.2122	U5=-0.3318X1-0.2437X2+0.7120X3-0.1897X4-0.0029X5-0.0338X6 V5=-0.3114Y1-0.2934Y2+0.7528Y3-0.2129Y4-0.0098Y5-0.0233Y6
6	0.0122	U6=-0.3979X1+1.1593X2-0.4347X3+0.0111X4-0.0475X5+0.0912X6 V6=-0.4017Y1+1.1471Y2-0.4205Y3+0.0080Y4-0.0433Y5+0.0834Y6

Table 3 shows the canonical correlation coefficient and canonical variables after the canonical transformation of original images. From the first pair of canonical variable, it could be seen that the larger the reflectivity of surface object after the nuclear explosion on TM 4, TM 5 and TM7, the larger the value of V1 is. TM1, TM2 and TM3 are the negative factors of V1. The strength of the reflectivity of visible spectrum of the surface object after UNE may reduce the value of V1. From the third pair of canonical variable, it can be seen that larger the reflectivity of surface object after UNE on TM1, TM2 and TM3, the larger the value of V3 is. Especially if the reflectivity on TM2 was strengthened, the value of V3 would be larger. TM 5 and TM7 are the negative loads of V3. If the reflectivity of the surface object after UNE on TM 5 and TM7 were strengthened, the value of V3 would be reduced. The corresponding MAD variables of the first pair and third pair of canonical variables are respectively MAD6 and MAD4. Integrated with the above MAD variable analysis, we can see the reflectivity of ground features after the nuclear explosion strengthens at visible band spectrum.

Combined with the other literatures and explosion phenomenon analysis, Pakistan explosion event caused the mountain shake with a rock slide and the ground surface temperature anomaly within certain scope may resulted in the surrounding object dry, which significantly changed the reflectivity of ground object after the nuclear explosion the reflectivity was strengthened at visible and near-infrared band spectrum. This is consistent with the analysis results after multivariate alteration detection.

IV. CONCLUSION

(1) Other UNE events were also chosen for anomaly detection in ground object by multi-spectral images, the satisfied results were acquired. It suggests that multi-spectral image is very suitable for the anomaly detection in ground object of the UNE in a large area, and the satellite images with higher resolution can efficiently illustrate the anomaly information of underground nuclear explosion.

(2) Based on multivariate alteration detection, this paper explored the multi-channel remote sensing image alteration detection. It can be seen that the premise of alteration detection is taken as the extreme condition for the canonical transformation of two pairs of random variables composed of original images. In this way, the correlation between each band and original images can be eliminated furthest; the alteration information can be highlighted obviously and extracted accurately [13]. This method is relatively universal.

(3) Through the processing after multivariate alteration detection, the correlations between the bands of the original images and the alteration information were studied. We drew the conclusion that the results of the anomaly of surface object in different bands were different. Combined with the surface phenomenon analysis of the UNE, the efficiency of this method is verified. If there is actually-measured ground spectral data, this method can provide more effective support to detect and analyze the anomaly of the UNE.

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