Change Detection for Reconstruction Monitoring based on Very High Resolution Optical Data

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Abstract—**Change detection techniques are widely used in environmental monitoring, however, the issue of best suitability of change detection techniques for a specific application, even study area is still unanswered. In case of reconstruction monitoring, difference-based change detection methods are compared and evaluated in detecting changes on the study area Banda Aceh by using very high resolution optical data in this paper. They are classical image differencing, iteratively reweighted multivariate alteration detection (IR-MAD) and IR-MAD incorporating some textural features. The experimental results show that IR-MAD method has the best performance. Compared with manually acquired reference data, the change detection map produced by IR-MAD method is satisfying and promising.**

I. INTRODUCTION

Natural hazards have dramatic influences on the affected regions which can severely hinder the normal life for the people in terms of damaged infrastructure (e.g. houses, streets, industry, electricity and water network). The recovery and reconstruction activities for the infrastructure play a vital role in re-establishing good living conditions. To undertake a comprehensive assessment for the reconstruction activities is significant to make sure that the reconstruction is proceeding in the required locations and along the right timescales. Change detection technique can provide an overview of the recent state of the reconstruction activities, which can help to support the reconstruction missions and supervise the appropriate utilization of the allocated funds.

Although a variety of change detection algorithms have been developed, research studies have shown that no single method is optimal and applicable to all cases [1]. It is not easy or even not possible to choose a suitable algorithm to implement for a certain application, since the data analysis depends on the specific investigated application, the kind of data available and even the study areas. Therefore, results in most operational applications are gained by visual analysis up to now [2]. Unfortunately, the visual interpretation is very time-consuming and labor-consuming, especially in the case of large urban areas. Automatic change detection methods can help the interpreters to do their job faster, more efficient and in a more standardized way.

Since probably no automatic change detection algorithm can deliver perfect results, the overall objective of this paper is to find semi-automatic method for the application of reconstruction monitoring through comparison of difference based methods (classical image differencing, iteratively reweighted multivariate alteration detection and IR-MAD combined with textural information), which uses very high resolution optical data. In this case, only the results of the automatic part have to be analyzed manually by operator instead of the complete data.

Section Ⅱ describes the workflow and approaches adopted in this paper. In the following section Ⅲ, the study area and test data chosen are introduced in detail. After implementing the methodology, section Ⅳ discusses the results of the paper. Finally, section Ⅴ gives a short conclusion.

II. METHODOLOGY

The general workflow of change detection implemented in the paper is shown in Fig. 1. The first important step is image preprocessing, which makes the two temporal images as similar as possible. It mainly includes image co-registration and radiometric correction. Image co-registration aims at making the corresponding pixels in the two temporal images relative to the same geographical position on the ground [3]. Accurate spatial registration is extremely necessary for change detection. Otherwise, lots of spurious changes will be produced. Usually sub-pixel RMS errors of co-registration should be ensured [4]. Due to some factors such as different acquisition time and various view angle of sensor, there are some changes that do not interest us. The radiometric correction step aims at reducing these differences of the two temporal images caused by the distinction in light and atmospheric conditions at two acquisition dates [3]. However, this step is not always necessary for the change detection methods. In this paper, classical image differencing needs radiometric correction absolutely. And histogram normalization is used to correct the images for image differencing. However, it is superfluous for the method of MAD due to that it is invariant to linear scaling, which means it is not sensitive to radiometric and atmospheric correction schemes [5]. After preprocessing steps, change detection algorithm is implemented. After that, thresholding technique often needs to be applied in order to differentiate

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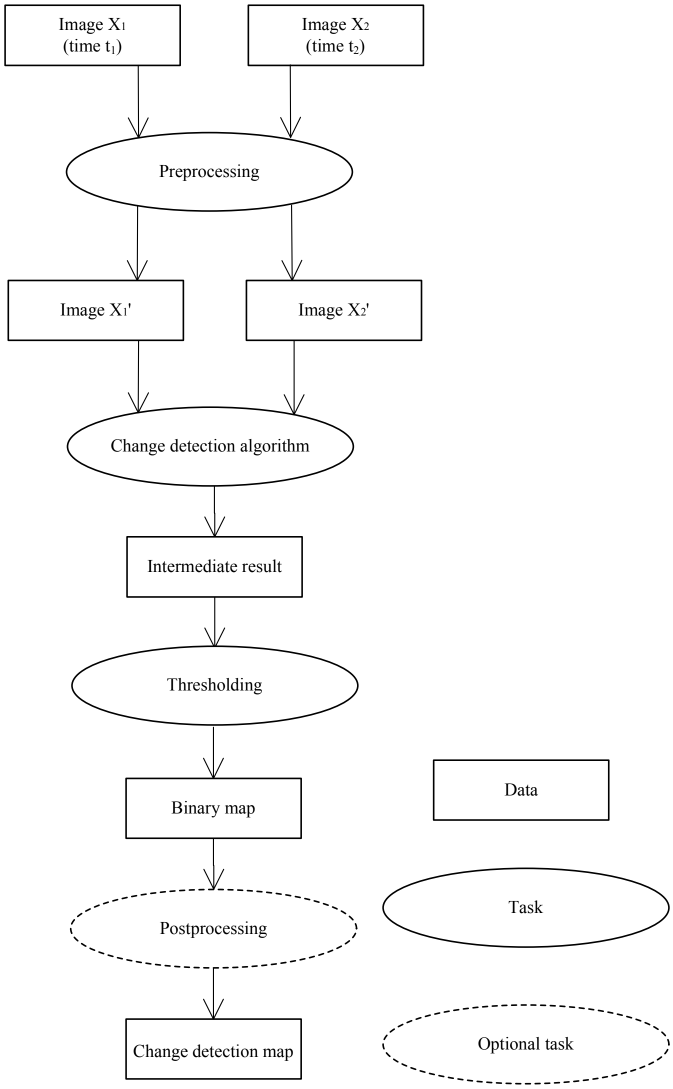


Figure 1. Flow diagram of change detection

changes from no change areas. In the final, postprocessing steps may be necessary to make the real changes more compact and the virtual ones thinner.

A. Classical Image Differencing Method

Image Differencing is mathematically the easiest and the most extensively used change detection approach that has been applied in various geographical environments [6]. This technique involves subtracting two spatially co-registered images acquired at different time pixel by pixel [1]. Ideally, the

value zero represents areas of no change while positive or negative values for changed areas in the difference image. Since many factors such as inaccurate co-registration can lead to virtual changes, the value that represents no change is never zero. Therefore, the critical step of image differencing is deciding where to place the threshold boundaries between change and no-change [6]. The thresholding method applied in this paper is to find an optimal threshold through comparing change detection maps obtained by assigning changing multiple of standard deviations from the mean for a selected small sample area with the related manually acquired reference data, and then applying the same threshold on the whole tudy area.

If image differencing is still applied on the multispectral data, how to select appropriate bands becomes a challenge, since different band may be suitable to detect distinct information [7].

B. IR-MAD Method

Avoid of band selection, another difference-based change detection method MAD that utilizes all the bands simultaneously is implemented on the multispectral data of the same area. The method is based on an established multivariate statistical technique-canonical correlation analysis (CCA). The MAD finds the difference between linear combinations of the original multispectral data from the two acquisition dates. It can be easily illustrated by Equation (1), where X and Y are vectors representing two multispectral images with variables at a given pixel, a_i and b_i are the coefficients given by the canonical correlation analysis. As CCA finds linear combination of the original multispectral data ordered by decreasing correlation between pairs, MAD transformation determines the difference between linear combinations of the original multispectral bands ordered by variance. A detailed analysis can be found in [5].

$$\begin{bmatrix} X \\ Y \end{bmatrix} \rightarrow \begin{bmatrix} a_k^T X - b_k^T Y \\ \vdots \\ a_1^T X - b_1^T Y \end{bmatrix} \quad (1)$$

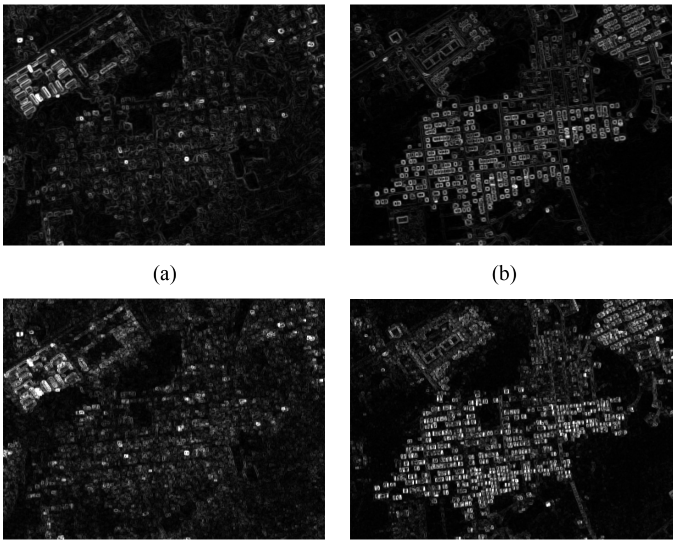
The IR-MAD method calculates original MAD variates firstly, and then in the following iterations, puts increasing attention on “difficult” observations which are the pixels whose change status over time is unsure. This is achieved through calculating a measure of no change based on the sum of squared, standardized MAD variates in each iteration [8]. The iterations are continued until the largest absolute change in the canonical correlations reaches a pre-set value, e.g. 10^{-3} in this paper. The sum of squared, standardized MAD variates for pixel j will follow a χ^2 distribution. The chi-square image incorporating all the information of MAD variates is defined by Equation (2), where i is number of bands.

$$chi-square = \sum_{i=1}^{k} \left(M_i\right)^2 \quad (2)$$

In this paper, the chi-square image is thresholded by some automatic local and global threshold methods, which is provided by the image analysis software ImageJ developed by Landini.

C. IR-MAD combined with Textural Information Method

Considering that textural features play an essential role in identifying objects of interest, some textural information is introduced as additional bands combined with the original multispectral bands. The idea is that the damaged areas should be rich in textural features compared with the same areas after reconstruction which mainly consist of regular buildings. The widely used texture modeling is grey level co-occurrence matrix [9] due to its simplicity and low computational complexity, which has been proved very efficient in texture modeling. The textural features introduced in this paper are sum variance and difference variance. The details about how to compute them can be found in [9]. As illustrated in Fig. 2, they look considerably different between the two images at different acquisition dates. The texture in QuickBird image looks irregular and coarse, whereas the boudaries of new building can be seen very clearly in GeoEye imagery. All the textural features in Fig. 2 are calculated within 3 × 3 pixel window, which makes a good distinction between the original two images. These two textural bands are then combined with original multispectral images to perform IR-MAD change detection method described above.



(a) (b) (c) (d)

Figure 2. Textural images: (a) sum variance (QuickBird); (b) sum variance (GeoEye); (c) difference vairance (QuickBird); (d) difference vairance (GeoEye)

III. Study Area and Test Data

A. Study Area

The study area chosen for this research is located at Banda Aceh in northern Sumatra, which experienced extensive tsunami on 26 December 2004. The tsunami causes severe damages to the infrastructure such as buildings and roads. The area has been reconstructed since the disaster.

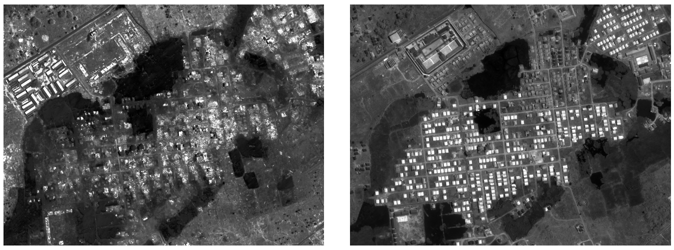
B. Optical Satellite Data

Two temporal images taken on the study area are selected. One is QuickBird imagery taken approximately eight months after the tsunami. The other is GeoEye imagery acquired after reconstruction work. The details of the test data are described in Table Ⅰ. In order to visualize the changes clearly, Fig. 3 illustrate the two normalized panchromatic images.

TABLE I. DESCRIPTION OF TEST DATA

Sensor	**Data Parameter**		
	Acquisition date	***Panchromatic resolution***	***Multispectral resolution***
QuickBird	2005-08-06	0.6 m	2.4 m
GeoEye	2009-06-16	0.6 m	2.4 m

In the paper, both the panchromatic and multispectral images of the study area are applied for change detection. The imageries at different acquisition time are orthorectified with Universal Transverse Mercator (UTM) projection and co-registered with the error 0.39 pixel in x direction and 0.57 in y direction.



(a) (b)

Figure 3. Normalized images of Banda Aceh: (a) QuickBird (2005); (b) GeoEye (2009)

C. Reference Data

In order to evaluate the performance of the methods, the reference data is acquired by visual/manual interpretation. As can be seen in Fig. 4, a large amount of buildings, few roads and two squares have been changed

Figure 4. Reference data (white means changes whereas black represents no change)

IV. Results and Disscussion

Comparison of the performance of change detection methods introduced is illustraed by Fig. 5, which displays ROC curves. It is obvious that MAD method outperforms the other methods, especially for image differencing. Unfortunately, it seems that incorporating texture information does not help improve the performance of MAD method for this urban area.

The selected change detection map by using MAD method is showed in Fig. 6 (a). It can be seen that there are some virtual changes, so we delete the changed regions with area below 5 pixels (the size of minimum building is around 5 pixel). Then the result is displayed in Fig. 6 (b). As can be seen

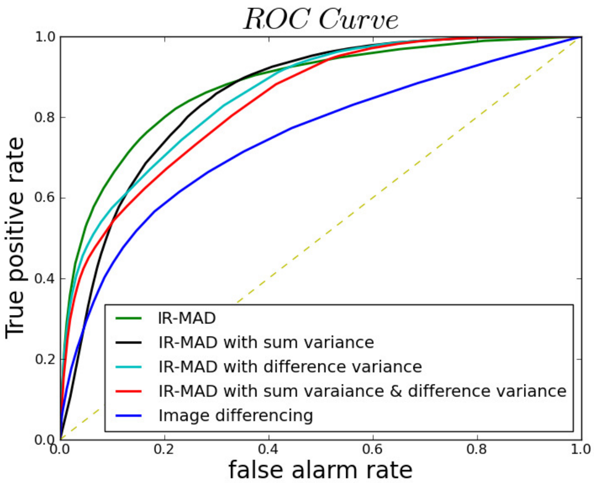
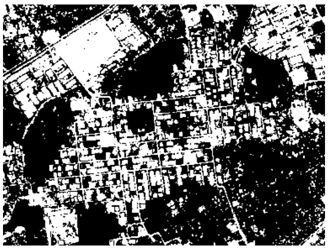
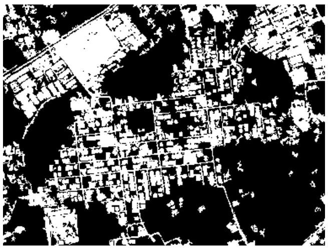


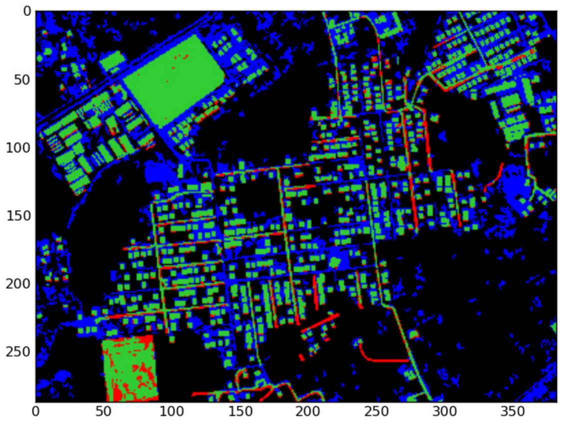
Figure 5. ROC curve for various change detection methods



(a)



(b)



(c)

Figure 6. change detection results: (a) change detection map using MAD; (b) change detection map after postprocessing; (c) the overlay of final change detection map and the reference data. The green, blue, balck and red match with true positives, false positives, true negatives and false negatives, respectively

in Fig. 6 (c), the overlay of change detection result and the reference data shows that almost all the buildings have been detected and few roads and very small part of the new square at the left corner of the image can not be detected. The reason may be the difference of grey values of these part in the two temporal images are not apparent. In addition, some blue area is related to the change of lake, which is not inculded in our reference data since we are not interested in it.

In order to analyze the accuracy of MAD quantitatively, some accuracy indicants based on error matrix are calculated. The completeness, correctness and overall accuracy are 83.94%, 46.07% and 77.20% respectively.

V. CONCLUSION

In this paper, difference-based change detection methods are compared and evaluated to detect changes for reconstruction monitoring of Banda Aceh. IR-MAD method is found to be the best in terms of ROC performance. The results of the IR-MAD method shows to be satisfying and can be regarded as the preliminary product for the subsequent manual interpretation.

ACKNOWLEDGMENT

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