A NEW RELATIVE RADIOMETRIC CONSISTENCY PROCESSING METHOD FOR CHANGE DETECTION BASED ON WAVELET TRANSFORM AND LOW-PASS FILTER

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ABSTRACT:

Considering the actual research purpose, this paper has shown the limitations of the existing radiometric normalization approaches and their disadvantages in change detection of artificial objects by comparing the existing radiometric normalization approaches, on the basis of which a preprocessing approach of radiometric consistency based on wavelet transform and spatial low-pass filter has been introduced. This approach separates the high frequency information and low frequency information by wavelet transform first. Then, processing of relative radiometric consistency based on low-pass filter is conducted to the low frequency parts. After the processing, inverse wavelet transform is conducted to obtain the result image. The experimental results show that this approach can reduce the influence of linear or nonlinear radiometric difference of multi-temporal images on change detection a lot.

1. INTRODUCTION

Most change detection approaches mainly depend on changes of spectral reflection values of remote-sensing image caused by change of objects. However, these changes can be caused by real change of objects, and can also be caused by many other factors such as imaging season, imaging time, imaging angle, solar altitude angle, meteorological conditions and covering extent of cloud, rain and snow. These factors all can influence the accuracy of change detection results significantly. So radiometric normalization is often needed before change detection. (Chavez 1996, Chen et al. 2002, Coppin et al. 2004, Du et al. 2002, Lillesand & Kiefer 1994, Song et al. 2001, Spanner et al. 1994, Spanner et al. 1990).

Radiometric normalization refers to elimination or decrease of inconsistency of the measured value by the sensor and spectral reflectance or spectral radiance of the object. It includes absolute radiometric normalization and relative radiometric normalization(Coppin et al. 2004, Elvidge & Lyon 1985, Elvidge et al. 1995, Du et al. 2002, Song et al. 2001, Schott et al. 1988). Absolute radiometric normalization mainly correct the radiometric distortion caused by condition or attitude of the sensor, sun illumination, atmospheric diffusion or atmospheric absorption, which is irrelevant to change of radiometric characteristics of object surface. Because it is expensive and impractical to get atmospheric parameters and ground objects for current data, and it is nearly impossible for historical data and wide- range regional research, absolute radiometric normalization is difficult to be realized in most cases (Chavez 1996). Change detection aims at multi-temporal images, and it is a relative operation between images, so radiometric characteristics of multi-temporal images that have been used for analysis needn't be absolutely right. They only need to be relatively consistent. Consequently, relative radiometric

normalization is mainly used during change detection. Taking an image as reference image, regulate the radiometric characteristics of another image to make it match the reference image(Hall et al. 1991).

The common relative radiometric normalization approaches can be classified into two types according to algorithm models. One is nonlinear normalization approaches, among which histogram matching is the most widely used. The other type is linear regression approaches, which often assume that linear relationship exists between the DN（Digital Number or Gray Value，DN）of the image to be corrected and the DN of the reference image(Ding et al. 2005; Yong et al. 2002), and among which the approaches that have better application results are simple image regression, pseudo-invariant features, dark set-bright set normalization, and no-change set radiometric normalization. For conventional image processing, relative radiometric normalization approaches are easy to be realized, so they are widely applied. However, different sensors have different features, and natural landscape of different regions shows different characteristics on the remote-sensing image, so one approach may lead to different effects when applied to different remote-sensing images. Consequently, the effects of different approaches can't be treated as the same. A proper approach should be chosen according to the application and data features.

During applications of change detection, it is found that the conventional relative radiometric normalization approaches may have the following problems when directly applied to change detection: first, for different sensors or multi-temporal images of the same sensor, radiometric distribution may not conform to linear relationship. If processing is conducted according to linear relationship, it may lead to wrong results. Second, histogram matching, the most widely used approach of the

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nonlinear relative radiometric normalization approaches, doesn't show satisfying effects during applications. Histogram and the image may not be in one-to-one correspondence; radiometric distribution can be easily changed into a disordered condition; and gray-scale loss may exist in the processing results of histogram matching. Third, the linear and nonlinear relative radiometric normalization approaches mentioned above all conduct mathematic calculation according to overall statistic characteristics of the image, not considering local characteristics of the image.
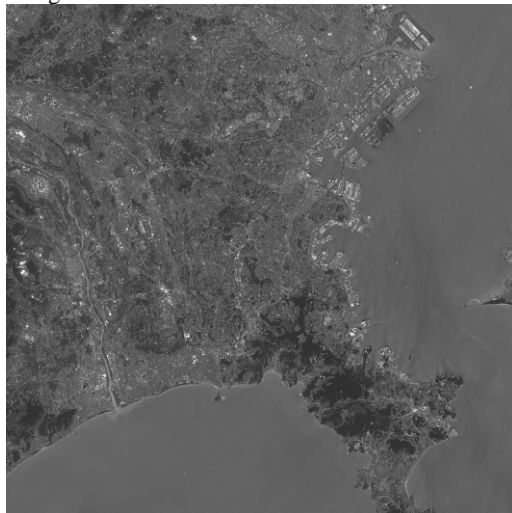
(a) 2003-08-25 Spot5 Original Image

(b) 2003-12-07 Spot5 Original Image

(c) a Processing Result of Mean-Standard Deviation Normalization

(d) a Processing Result of Histogram Matching Normalization

Fig.1 Comparison of Conventional Radiometric normalization Results

It can be seen from Fig.1 that both linear regression approach and histogram matching are out of function to the images with nonlinear radiometric difference. Not only radiometric difference of the water area hasn't been eliminated, radiometric features of the land have also been damaged to some degree with the influence of water statistics. So if such processing results are directly used in change detection, wrong results will be obtained.

In order to solve both linear and nonlinear radiometric difference during radiometric processing of change detection , radiometric normalization approach that has been adopted must consider overall statistical information and two dimensional distribution information at the same time. Consequently, a new relative radiometric normalization approach is put forward in this paper: Processing of Relative Radiometric Consistency Based on Wavelet Transform and Low-pass Filter. This approach doesn't pursue optimal radiometric features of result image. The radiometric features only need to meet the need of change detection. Owing to the fact that its train of thought is different from that of the conventional relative radiometric

normalization approaches, this approach is also called "Processing of Relative Radiometric Consistency" in this paper.

2. METHOD

2.1 Wavelet Transform Principle

Wavelet transform is a time-scale(time-frequency) analysis method of signals with the feature of multi-resolution analysis. It has the ability of showing local features of the signal both at the time domain and frequency domain. It is a time-frequency localized analysis method with fixed window size, changeable window shape, and changeable time window and frequency window.

Wavelet can be defined as follows: $\forall \psi(t) \in L^2(R)$. If its Fourier transform $\psi(\omega)$ meets the following condition:

$$\int_{-\infty}^{\infty} \frac{|\psi(\omega)|^2}{|\omega|} d\omega < \infty \qquad (1)$$

Then $\psi(t)$ is called fundamental wavelet or mother wavelet, and formula (1) is called permissible condition of wavelet.

From the definition of wavelet, it can be known that wavelet function is not only required to be concussive, namely contain a certain frequency feature, it is also required to have some limitations. That is why $\psi(t)$ is called wavelet. Stretch, shrink or translate $\psi(t)$, the fundamental wavelet (mother wavelet):

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi(\frac{t-b}{a}) \ a, b \in R, a \neq 0 \qquad (2)$$

$\psi_{a,b}(t)$ is called wavelet basis function, of which a is scale factor, and b is displacement factor.

Assume that $\psi(t)$ is fundamental wavelet, and $\psi_{a,b}(t)$ is the basis function of consecutive wavelet defined in accordance with formula (2). If $f(t) \in L^2(R)$, consecutive wavelet transform can be defined as follows:

$$Wf(a,b) = \langle f(t), \psi_{a,b}(t) \rangle = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} f(t) \psi^*(\frac{t-b}{a}) dt \qquad (3)$$

Consecutive wavelet inverse transform can be defined as follows:

$$f(t) = \frac{1}{C_\psi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} Wf(a,b) \psi(\frac{t-b}{a}) \frac{dadb}{a^2} \qquad (4)$$

Wavelet basis function determines the effect and efficiency of wavelet transform. Wavelet basis function can be selected freely. The simplest Haar wavelet has been adopted by the experimental system in this paper for separation of high and low frequency. For details of wavelet transform and wavelet analysis, please refer to the relevant document.
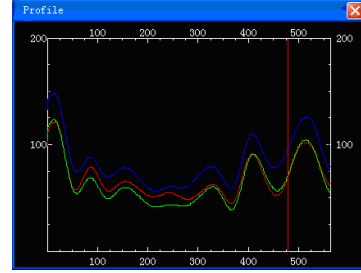Haar wavelet:

$$\psi(t) = \begin{cases} 1 & 0 \le t < \frac{1}{2} \\ -1 & \frac{1}{2} \le t < 1 \\ 0 & \text{others} \end{cases} \qquad (5)$$

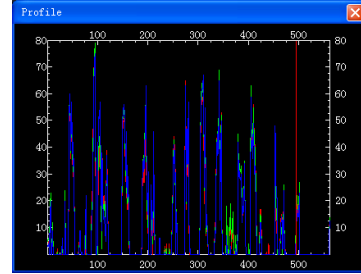$$\psi(\omega) = i \frac{4}{\omega} e^{-\frac{i\omega}{2}} \sin^2(\frac{\omega}{4}) \qquad (6)$$

2.2 Algorithm
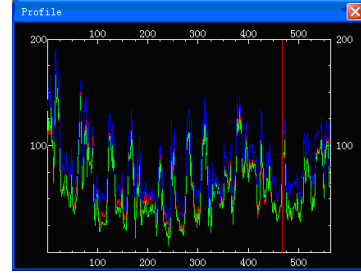
(a)

(b)

(c)

Fig.2　Diagram on Separation of High frequency and Low frequency of the Remote-sensing Image（The red, green and blue curves stand for three wave bands respectively.）,（a）Gray Scale Profile of a Line of Remote-sensing Image （b）Low frequency Part of the Curves in Image a （c）High frequency Part of the Curves in Image a

As shown in Fig.2, in remote-sensing image, it is low frequency information that mainly stands for radiometric lightness distribution, and high frequency information shows the texture details. So radiometric lightness difference of images is mainly reflected on low frequency parts of images. If low frequency information of two images to be corrected is adjusted to be approximately consistent, radiometric distribution features of two images come to be consistent. Consequently, a new thought for relative radiometric normalization can be obtained: extract low frequency parts of two images, and adjust the low frequency part of the image to be corrected, then relative radiometric normalization can be realized. Because the low frequency of the image can be obtained by low-pass filter first,

this relative radiometric normalization approach is called Processing of Relative Radiometric Consistency Based on Low-pass Filter (LPF), the procedure of which is as follows:

First, assume that f_1 is the image to be corrected and f_2 is the reference image.

(1) Smooth the images f_1 and f_2 by spatial domain low-pass filter to obtain low frequency images f_1^L and f_2^L that can approximatively stand for lightness distribution of image.

(2) Use difference (or ratio) of the original image f_1 and the low frequency image f_1^L to get f_1^H, which can be approximatively regarded as high frequency part of f_1.

(3) Adjust f_1 by the relationship between f_1^L and f_2^L to get correction result f_1'. The simplest adjusting method is the difference method as follows:

$$f_1'(x, y) = f_1 - (f_1^L - f_2^L)$$
$$= f_1 - f_1^L + f_2^L \qquad = f_1^H + f_2^L$$

(7)
or
$$f_1'(x, y) = f_1 / (f_1^L / f_2^L)$$
$$= f_1 * (f_2^L / f_1^L)$$
$$= f_2^L * (f_1 / f_1^L) \qquad = f_2^L * f_1^H$$

(8)
This processing is equivalent to the procedure that to replace the low frequency part of the image to be corrected with the low frequency part of the reference image. Because in practical operation, separation of high frequency and low frequency is only a relative processing, still a large quantity of high frequency texture information exists in f_2^L the low frequency part of the reference image. Consequently, the high frequency of the image to be processed may be damaged during the procedure of processing with formula (7) or (8). In order to adjust radiation and protect image texture at the same time, wavelet transform is introduced on the basis of the approach mentioned above. During the processing of relative radiometric consistency based on wavelet transform and low-pass filter, wavelet transform is used for pre-separation of high frequency and low frequency parts. After wavelet transform, processing of relative radiometric consistency based on low-pass filter only need to be conducted to the low frequency part, and the high frequency part doesn't take part in operation, then reverse transform is conducted to obtain the result image. In this way, the influence of radiometric processing on image texture is controlled only to the low frequency part, so radiometric normalization is realized, and texture information can be protected to the maximum extent.

First, assume that f_1 is the image to be corrected and f_2 is the reference image. Then the specific algorithm of relative radiometric consistency processing of images is as follows:

(1) Wavelet transform is conducted for n times to f_1 and f_2, so that low frequency parts of the image f_1^L and f_2^L, and high frequency parts of the image f_1^H and f_2^H are

obtained.

(2) Smooth f_1^L and f_2^L with spatial mean filter to obtain low frequency images f_1^{LL} and f_2^{LL} that can approximatively show lightness distribution of image.

(3) Use difference (or ratio) of f_1^L and f_1^{LL} to get f_1^{LH}, which can be approximatively regarded as high frequency part of f_1^L.

(4) Adjust f_1^L and f_2^L by the relationship between f_1^{LL} and f_2^{LL} to get correction result $f_1^{L'}$. The specific adjusting method is as follows:

$$f_1^{L'}(x, y) = f_1^L - (f_1^{LL} - f_2^{LL})$$
$$= f_1^L - f_1^{LL} + f_2^{LL} \qquad (9)$$
$$= f_1^{LH} + f_2^{LL}$$

or

$$f_1^{L'}(x, y) = f_1^L / (f_1^{LL} / f_2^{LL})$$
$$= f_1^L * (f_2^{LL} / f_1^{LL}) = f_2^{LL} * f_1^{LH} \qquad (10)$$

(5) Replace f_1^L with $f_1^{L'}$.

(6) Reverse transform is conducted to wavelet transform result of f_1 to get radiometric processing result. Take the image in Fig.1 as an example, and flow diagram of algorithm is as shown in Fig.3.
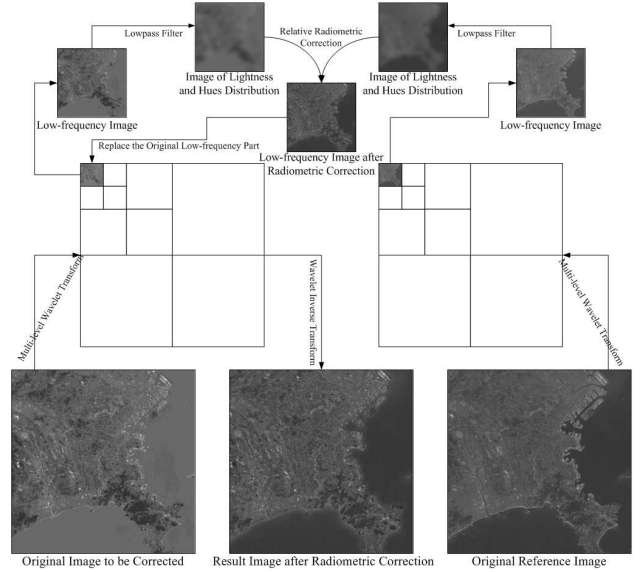

Fig.3 Flow Diagram of Algorithm for Relative Radiometric Consistency Processing Based on Low-pass Filter and Wavelet Transform

In order to prove that it is helpful to introduce wavelet transform into the approach of radiometric consistency processing based on low-pass filter for texture production, the following will compare and analyze the image in Fig.6 processed at different scales.

Standard deviation is used, for it can measure two influences of algorithm on image. One is that it can measure to which extent the texture information of reference image has been mixed into result image. The other is that it can measure to which extent

the texture of original image has been damaged by the radiometric processing algorithm.

For the first influence, it can be known from the principle of the approach of relative radiometric consistency processing based on low-pass filter that it is inevitable for texture information of reference image to enter result image. Consequently, after the original image is processed, its texture will draw close to that of the reference image. Reflected on the standard deviation, it will be that the standard deviation of result image is between that of the original image and reference image.

For the second influence, it can be known from the principle of the approach of relative radiometric consistency processing based on low-pass filter that the way of separating high frequency and low frequency is to remove low frequency information from the original image. Because some high frequency information may also be mixed in the low frequency information, the high frequency tends to be damaged during processing.
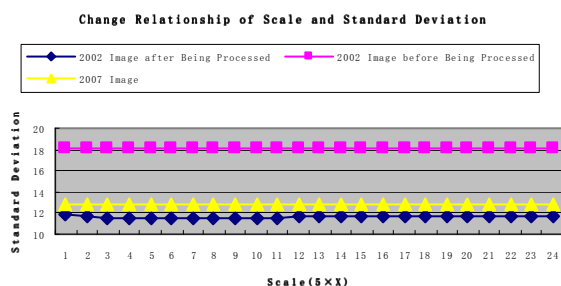

Fig. 4 Change Relationship Curves of Low-pass Filter Scale and Standard Deviation of Result Image with the Approach for Relative Radiometric Consistency Processing Based on LPF
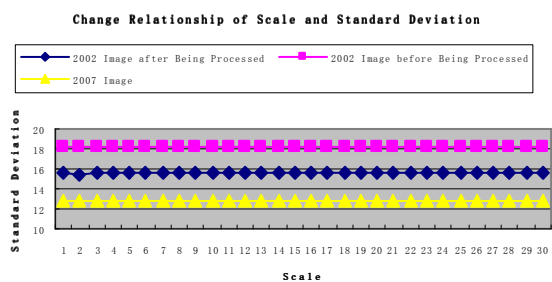

Fig.5 Change Relationship Curves of Equivalent Scale and Standard Deviation of Result Image with the Approach for Relative Radiometric Consistency Processing Based on WLPF

Consequently, during radiometric processing, the two influences are integrated. Fig.4 shows that image standard deviation after being processed with the approach based on low-pass filter is lower than that of the original image and reference image , which means that the texture information of the image has been damaged by this approach. While in Fig. 5 standard deviation of the result image is between that of the original image and reference image, and is closer to that of the original image. It means that when relative radiometric consistency

processing based on low-pass filter is conducted on the basis of wavelet transform, texture information of the original image can be protected very well.

3. RESULTS AND DISCUSSION

The aim of above relative radiometric consistency processing is for change detection. Consequently, effect of the approach proposed in this paper on change detection need to be analyzed. In order to show the efficiency of the approach proposed in this paper for processing nonlinear radiometric difference between images during change detection, this experiment adopts the images Nanjing 2002 and Nanjing 2007 to simulate the images of nonlinear radiometric difference caused by polarization, as shown in Fig.6.
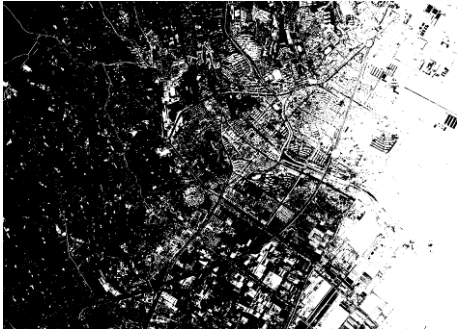

(a) Nanjing 2002 Polarized Image -3m
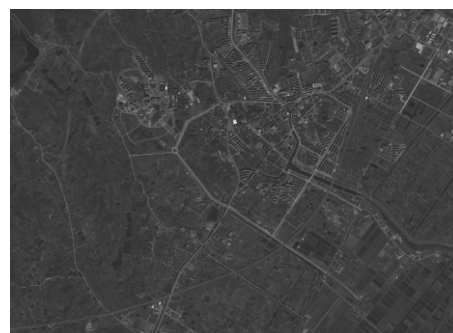
(b) Nanjing 2007 Image-3m
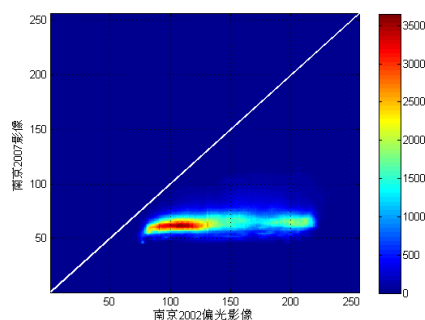
(c) United Scatterplot of a and b
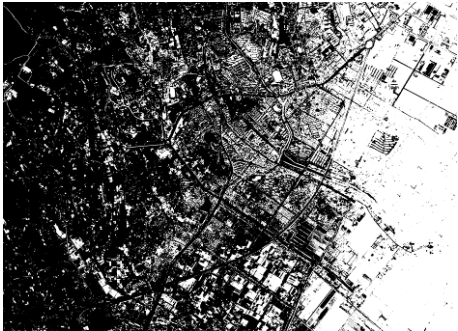
(d) Result of Change Detection with a and b

(e) Normalization Result of a with Histogram Matching
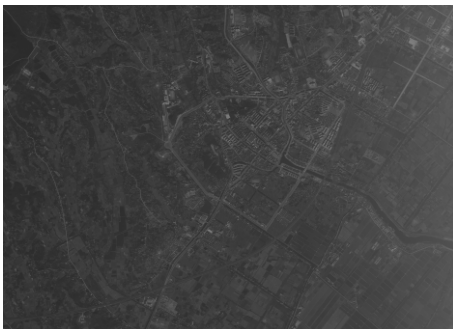

(f) Normalization Result of a with Linear Regression

(g) Normalization Result of a with Linear Regression

(h) Result of Change Detection with g and b

(i) Normalization Result of a with Approach Proposed in this Paper

(j) Result of Change Detection with i and b

Fig.6 Comparison on Abilities of Processing Nonlinear Radiometric Difference

As shown in Fig.6, (a) is a polarized analog image of Nanjing 2002 image. Lightness distribution in this image is uneven, darker on the left and lighter on the right. Lightness distribution in image (a) is even. As shown in (c) the scatter plot, radiometric difference of images (a) and (b) is very complicated. So if change detection is conducted directly, a wrong result will be obtained as shown in (d). (e) shows the correction result of (a) with histogram matching approach, from which it can be seen that nonlinear radiometric difference hasn't been eliminated with this approach. Instead, it has caused gray scale loss, and compared with (a) image quality is much poorer. (g) is the normalization result of (a) with conventional linear regression approach. It can be seen from (h) that processing effect of linear regression is much better than histogram matching, because spatial radiometric difference of the image is nonlinear, though left-right polarization exists. From the scatter plot, it can be seen that the main parts still nearly have a linear relationship. Though the linear relationship is not obvious, the effect is still better than that of histogram matching. (i) shows correction result of (a) with approach proposed in this paper. This approach pays attention to radiometric consistency processing in spatial distribution, so the lightness distribution of result

image (i) has already been essentially consistent with (b). Consequently, accuracy of change detection result with (i) and (b) shown in (j) nearly hasn't been affected by polarization.

In addition, it can be known from arithmetic principle that no matter what radiometric consistency processing is based on, low-pass filter or wavelet and low-pass filter, the key is low frequency information extraction, which is closely related with template scale of the filter and frequency of wavelet transform. So equivalent scale determined by filter scale and wavelet transform frequency determines the result of radiometric processing and finally influences accuracy of change detection. Consequently, the experiment in Fig.3 with different scales has been analyzed, and the result is as shown in Fig.7.
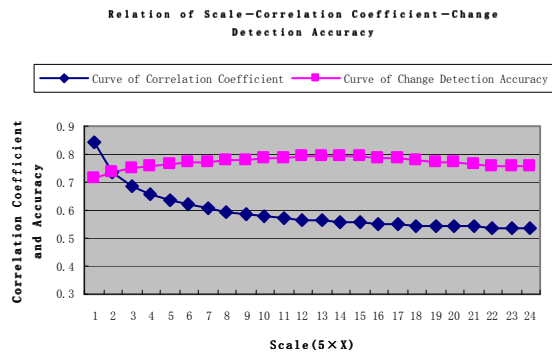

Fig.7 Curves of Scale, Change Detection Accuracy and Correlation Coefficient

It can be seen from curves in Fig.7 that when radiometric processing is conducted at small scales, change detection accuracy is quite low because of interference of the texture of reference image. With the increase of scale, accuracy is improved gradually. However, when the scale increases to a certain degree, accuracy begins to decreases gradually and changes to be steady. This suggests that when scale increases to a certain degree, the influence of radiometric processing on accuracy of change detection declines. Research shows that when scale of the target of interest is much smaller than that of the equivalent filter, its influence on change detection can be neglected.

From the experiment mentioned above, it can be seen that the processing approach of relative radiometric consistency based on wavelet transform and low-pass filter put forward in this paper is efficient in eliminating nonlinear radiometric difference of images, and is helpful to promote change detection accuracy.

4. CONCLUSION

Most change detection approaches are sensitive to image radiometric features, so radiometric processing is often needed before change detection to make radiometric features of multi-temporal images consistent. In practice, radiometric features of multi-temporal images may not conform to linear relationship, so linear regression, which is on the on the premise that radiometric features of images conform to linear relationship, often has poor results. In view of practical needs, a processing approach of relative radiometric consistency based on low-pass filter(LPF) has been put forward in this paper, on the basis of which wavelet transform is introduced, so that a processing approach of relative radiometric consistency based on wavelet

transform and low-pass filter （WLPF） has been proposed. Taking the consistency of radiometric features between images in spatial distribution as a rule, this approach gives consideration to both the whole and parts. So this approach not only can be used for processing relative radiometric consistency of images, but also can be used for eliminating tiny radiometric difference around the jointing line during image jointing and image updating. Experiments have shown that this approach is effective when used for processing radiometric consistency during change detection, and can also be widely used in other ways.

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