SAR image change detection algorithm based on stationary wavelet and bi-dimensional intrinsic mode function

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SAR image change detection algorithm based on stationary wavelet and bi-dimensional intrinsic mode function

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Abstract. Speckle noise in synthetic aperture radar (SAR) image is produced by the coherent imaging mechanism, which brings a great impact on the change information acquisition of multi-temporal SAR images. Two-dimensional stationary wavelet transform (SWT) and bi-dimensional empirical mode decomposition (BEMD) are the non-stationary signal processing theory of multi-scale transform. According to their implementation process and SAR image characteristic, this paper proposed a new multi-temporal SAR image change detection method based on the combination of the stationary wavelet transform and the bi-dimensional intrinsic mode function (BIMF) features, called SWT-BIMF algorithm. The contribution of the new algorithm includes two aspects. One is the design of the two selections of decomposition features, that is, the speckle noise filtering; another is the selected features to perform the enhance processing, so more effective change information will obtain. The feasibility of the SWT-BIMF algorithm is verified by the measured SAR image data, and good experimental results are obtained.

1 Introduction
Wavelet transform is a multi-scale time-frequency analysis method, which is an important part of modern signal processing, and it can well process the non-stationary signal. When the image is decomposed by two-dimensional discrete wavelet, a low frequency coefficient sub-image and three high frequency coefficient sub-images will be obtained at each decomposition scale. The low frequency coefficient sub-image mainly contains the background or trend information, while the high frequency coefficient sub-image contains noise, geometry and edge information. In essence, wavelet decomposition is a low-pass filter, which has been widely used in many fields, such as image filtering, feature extraction, image compression [1-3]. Two-dimensional discrete wavelet transform performs the down two sampling operations when it decomposes an image. So the size of the coefficient sub-image of a scale is only a half of upper scale coefficient sub-images, which is not conducive to the extraction and processing of the image features. The two-dimensional stationary wavelet transform (2D-SWT) overcomes this weakness, and the size of each coefficient sub-image is as same as the original image.

Empirical mode decomposition (EMD) is also a kind of multi-scale modern signal processing method, and it is also a low pass filter. A typical advantage of EMD is that it is a fully data-driven adaptive filter. It does not need any prior knowledge to adjust the filter structure by the data characteristic itself. Therefore, it overcomes the problem that the wavelet decomposition needs to select the basis function and decomposition scale, which is very suitable for nonlinear and non-stationary signal processing, and it has been widely used in different fields [4-6]. Since the empirical mode decomposition theory was proposed by Huang et al. in 1998 [7], it has been developed and perfected [8, 9]. Because one-dimensional EMD does not consider the spatial relationship of pixels when it processes the two-dimensional image signal, and the computing speed is lower, Billing et al.
the bi-dimensional empirical mode decomposition (BEMD) theory [10], and it is directly used to decompose and process an image [11].

SAR imaging is a kind of active microwave remote sensing imaging, can acquire remote sensing data under all-weather and all-time, so it is an indispensable technology means of earth observation, especially obtaining the dynamic monitoring and change information [12-13]. At the same time, the SAR image is non-stationary information, and its imaging mechanism is essentially different from the optical imaging. Therefore, the SAR image has its own unique features. It is difficult to obtain satisfactory results in SAR image processing by the general methods. According to the SAR imaging mechanism and the advantages of SWT and BEMD, this paper proposed a new multi-temporal SAR image change detection algorithm which combines the two-dimensional SWT and BEMD theories. Because BEMD directly extracts the bi-dimensional intrinsic mode function (BIMF) feature components, the new method is called the change detection algorithm based on stationary wavelet transform and bi-dimensional intrinsic mode function (SWT-BIMF).

The biggest disadvantage of SAR image is that the coherent imaging mechanism brings a lot of speckle noise, which brings great challenge to the interpretation and application of SAR images. The greatest contribution to the SWT-BIMF algorithm proposed in this paper is that it designs the two filter processing and the BIMF feature selection, enhancement and fusion processing. It not only reduces the influence of speckle noise on the detection results, but also gets good change information.

2 SWT-BIMF algorithm description

Multi-temporal SAR image change detection refers to using SAR images obtained from the same target scene at different times to perform the corresponding processing and analysis operations, and to obtain the dynamic information or phenomenon of the target areas. Therefore, it is usually to use different time SAR image to extract the target change information, but it is often seriously affected by speckle noise. SWT-BIMF algorithm not only can effectively reduce the effect of speckle noise on SAR images, but also can improve the signal to noise ratio of SAR image, get richer target details and geometric information, and obtain more accurate change information. The flow chart of SWT-BIMF algorithm is shown in Fig. 1, and the algorithm includes the following steps and its main steps are as following.

1) Input different temporal SAR images.
2) Perform the pre-processing to the input SAR images, including the radiation correction, geometric correction, and the registration between different temporal images.
3) Perform the two-dimensional stationary discrete wavelet transform. After the SAR images of different time are decomposed by 2D-SWT, a low frequency coefficient sub-image and three high frequency coefficient sub-images are obtained at each decomposition scale. The noise is mainly contained in the sub-images of high frequency coefficients. Therefore, when removing the high frequency coefficient sub-images, most of the speckle noise is removed, and a small amount of detail information is removed, too. However, in the following processing steps, details information will make strengthened processing, which can make up for those lost information.
4) Extract the low frequency information after wavelet decomposition. Because the high-frequency sub-images contain large amounts of noise, including inherent speckle noise in SAR coherent imaging and other noise, through the processing of only extracting the low frequency approximate information sub-image and abandoning the high frequency sub-images, this can greatly reduce the influence effect of speckle noise. Note that in the SWT-BIMF algorithm, the wavelet decomposition scale is set to be one. Because of the increase of the decomposition scale, the information in the high frequency sub-image is not noise, but the edge and geometric details information.
5) Perform the processing of bi-dimensional empirical mode decomposition. BEMD is a fully data-driven adaptive signal processing theory, the decomposition basis function of the data is determined by the data itself, and it is very suitable for non-stationary information processing. After the low-frequency coefficients sub-image is decomposed by BEMD, the BIMF feature components of
different frequencies and a residual can be obtained. Decomposition scale from small to large, the frequency of BIMF from high to the end, the smaller the scale is and the more the noise is.

(6) Get BIMF feature images. After the low-frequency approximate coefficient sub-image is decomposed by BEMD, one can extract the BIMF features of the low frequency sub-image at different scales with different temporal SAR images, so here it called the SWT-BIMF feature.

(7) Get the final SWT-BIMF feature image. After obtaining the SWT-BIMF features of different scales, it is necessary to select the SWT-BIMF features of each scale to make the enhanced and fused processing. Finally, the SWT-BIMF features of each different time SAR image can be obtained.

(8) Produce the feature difference image. The different temporal SWT-BIMF feature images perform the subtraction operations pixel by pixel, and the feature difference image is obtained.

(9) Produce the change detection threshold. Using the expectation maximization (EM) algorithm processes the feature difference image and obtains the change detection threshold. EM algorithm is an unsupervised method, but it is also determined by the characteristics of the data itself.

(10) Obtain the change detection results. The amplitude of each pixel of the feature difference image is compared with the threshold. If the grey value of the pixel is greater than the threshold, it is considered that the changes happen; on the contrary, if the grey value of the pixel is less than or equal to the threshold, there is no change.

3 Experimental results and analysis
In order to verify the feasibility and correctness of the SWT-BIMF change detection algorithm, the measured SAR image data performs the compared experiments, and the experimental image data are shown in Fig. 2. The SAR images shown in Fig. 2(a) and Fig. 2(c) are from the Canadian RADARSAT satellite, the imaging area is Bengbu.
Figure 2 Original SAR images and SWT-BIMF feature image. ((a) the original SAR image at time $t_1$, (b) the SWT-BIMF feature image at $t_1$, (c) the original SAR image at time $t_2$, (d) the SWT-BIMF feature image at $t_2$.)

Figure 3 Results obtained by the SWT-BIMF algorithm. (a) Flooded area, (b) no flooded area, (c) all results of change detection.)
area, Anhui, China, and the imaging time was the summer of 2001 and 2005, respectively. Fig. 2 (a) is the SAR image before the flood, and Fig. 2 (c) is the SAR image after the flood. What Fig. 2 (b) and Fig. 2 (d) show are the SWT-BIMF feature images of Fig. 2(a) and Fig. 2(c), respectively. The experimental results are shown in Fig. 3 and Fig. 4. Here the result of the SWT-BIMF change detection algorithm is shown in Fig. 3 and the result that Fig. 4 shows is obtained by directly using the original SAR image. Fig. 3 (a) and Fig. 4 (a) indicate the backscattering weakening region; the backscattering enhancement regions are shown in Fig. 3 (b) and Fig. (b); no changed regions are shown in Fig. 3(c) and Fig. 4(c). It can be seen from Fig. 3 and Fig. 4 that the results shown in Fig. 3 are better than those shown in Fig. 4. This shows that the change detection results obtained by the SWT-BIMF algorithm are better than that of the original SAR images. The reason is that SWT-BIMF can obtain more details and geometric information, and can effectively restrain the speckle noise. The experimental results show that the SWT-BIMF algorithm can be used to detect the change information of multi-temporal SAR images, and it is not only feasible, but also can get good results.

![Image]

Figure 4 Results obtained through directly using the original SAR images. (a) Flooded area, (b) no flooded area, (c) all results of change detection.)

4 Conclusion
The SAR has the ability to obtain data from all-weather and all-time, and it is an important technical means for the dynamic monitoring and information acquisition. However, the speckle noise generated by the SAR coherent imaging mechanism brings great interference to the change information
acquisition, and affects the accuracy of the change information. SWT and BEMD are two kinds of multi-scale analysis methods, and they are suitable for processing non-stationary signal of SAR images. Through the selection of the decomposed features, it realizes the filtering processing of speckle noise, so as to effectively reduce the effect of speckle noise. The SWT-BIMF algorithm proposed in this paper can not only reduce the influence of speckle noise, but also get more accurate change information, which has been verified by experimental results.

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