NSCT domain image fusion, denoising & K-means clustering for SAR image change detection

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Abstract— The change detection in SAR (synthetic aperture radar) images mainly aims to obtain a reliable change map. The existing method based on log ratio difference image and k-means clustering gives fair results. Efficiency of the change map can be increased in two ways: 1) by increasing the efficiency of the difference image by using a fused difference obtained by fusing log-ratio and gauss log ratio difference images. 2) by means of using an improved fusion technique such as NSCT. An unsupervised change detection of multi-temporal SAR images combining image fusion and denoising using NSCT (Non Sub-sampled Contourlet Transform) and clustering approach is proposed. Difference image is obtained by fusing log-ratio and gauss log ratio image. NSCT is used to fuse the difference images, reduce the effect of noise and feature map construction. The final change map is obtained by clustering the feature vector into two classes: changed and unchanged class. The combination of image fusion, NSCT noise reduction and the feature clustering is expected to give a better change map than the existing techniques.

Keywords— DWT, NSCT, NSSC, ground truth, Donohov threshold, SSIM, fmi, k-means clustering.

1. INTRODUCTION

Change detection aims for obtaining a reliable change map of the multitemporal images over the same geographical area to get the information about the changed and unchanged areas. Multitemporal images are the images obtained over the same geographical area at different time [1]. The process of change detection involves mainly two steps: 1) generating a difference image and 2) clustering the features to obtain the final change map. The satellite image change detection is a very difficult process due to the presence of speckle noise. Speckle noise is a noise which inherently present in the radar [2]. And the noise is multiplicative in nature so it is very difficult to process and denoise the image. In order to get a reliable change map difference image via two operators, image fusion, NSCT [3] and k- means clustering techniques are incorporating as part of this work. So the change map will be more accurate and is more close to the ground truth of the actual dataset. Ground truth is the actual change map of the multitemporal dataset.

The major techniques used are: difference image operators, image fusion using DWT, NSCT (Non Subsampled Contourlet Transform) and k-means clustering. The first step for satellite image change detection is the generation of difference image. The difference image obtained through a single operator does not provide satisfactory result due to the presence of speckle noise. So instead of using a single operator here two operators such as log ratio and gauss log ratio operators are used to produce the initial difference image. Then the difference images obtained via two operators are combined using image fusion technique via DWT (Discrete Wavelet Transform). The image fusion technique improves the spatial information by retaining the relevant pixel information that contains the change [3]. The features are extracted from the fused difference image through NSCT operator. The obtained NSSC [4] (Non Subsampled Contourlet Coefficients) is then denoised using Donohov threshold [4], which reduces the effect of speckle noise.

The application of change detection involves remote sensing, terrain change identification, hazard detection *etc*. The main objective of this paper is to obtain a reliable change map and which is obtained by increasing the efficiency of the difference image and by increasing the efficiency of the change map. Image fusion and NSCT techniques are also used to improve the efficiency. The image fusion technique combines the most desirable characters of the difference images and the NSCT extracts the features from the fused difference image and do the denoising process as well. NSCT is the non subsampled version of contourlet transform, having the features such as shift invariance, good localization, directionality, multi resolution *etc*. The shift invariance and denoising capability makes the NSCT more advantageous than contourlet transform. This makes NSCT to capture the geometric details, object information and edge information very well even if the effect of noise is more. The output of NSCT processed image is then clustered to get the final change map. The reliability of the proposed method are analyzed using the ground truth of the dataset. The ground truth represents the true information regarding the geographical area that has been considered. The techniques make the changed portion more homogeneous.

2. PROPOSED METHOD

2.1 Problem formulation

The existing method associated with the satellite image change detection suffers the effect of speckle noise. In addition to presence of speckle noise the effect of sensor noise, illumination variation, non uniform attenuation or atmospheric absorption causes an unreliable change map. Speckle noise is a noise which inherently present in the radar itself occurred due to the backward reflections from the object. And this noise is multiplicative in nature causing an unreliable change detection process for the multi temporal image dataset. Speckle noise is a noise which inherently present in the radar itself occurred due to the backward reflections from the object. And this noise is multiplicative in nature causing an unreliable change detection process for the multi temporal image dataset.

2.2 Method

Initially, two multi temporal images, {X1, X_2} are considered and the difference images are obtained via two operators such as log ratio and gauss log ratio operator. Log ratio difference image find outs the log difference associated with the input dataset and the gauss log ratio operator find out the log of the image and then multiply it with a Gaussian low pass filter so that the effect of multiplicative speckle noise can be reduced. These two operators helps to obtain the initial change image and also it convert the multiplicative nature of the speckle noise in to an addictive one. Then the two difference images are combined using efficient image fusion K-means clustering K means is an unsupervised clustering method to partition the difference image into two classes: changed and unchanged, so the obtained fused difference image retains the most desirable features associated with the difference image with less spectral distortion and complexity. The two fusion results are undergone with same procedure such as NSCT denoising and k-means clustering operation. And the two methods are compared finally, The features such as coefficients associated with changes are obtained through NSCT decomposition for two levels. Denoising operation is also performed using NSCT since the effect of speckle noise is dominant even after the image fusion operation. NSCT (Non Sub sampled Contourlet Transform) is the shift invariant feature of contourlet transform having good frequency characteristics and is built upon iterated non separable filter bank to obtain shift invariance. The denoised NSCT coefficients are then clustered using suitable clustering approach such as k-means clustering to obtain the final change map. So that the final change map for the input can be obtained and the approach is less complex.

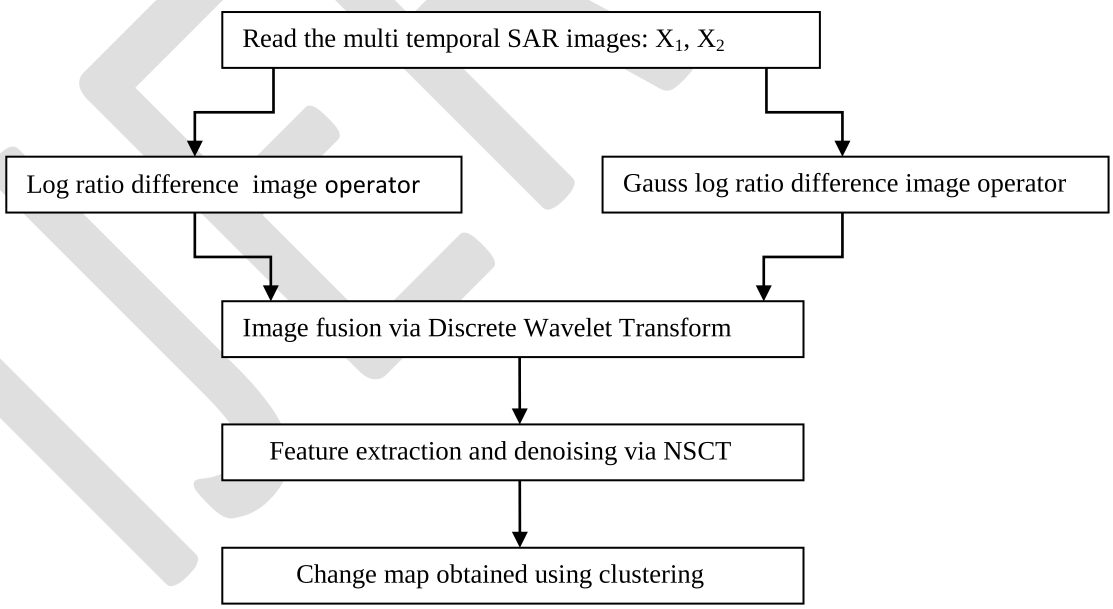


FIGURE 1: PROPOSED METHOD

3. DIFFERENCE IMAGES

The initial difference image is generated using ratio operators such as log ratio and Gauss log ratio difference image operator. These two difference image finds the major change associated with the multi temporal input images. The difference images are produced via two operators such as log ratio and Gauss log operator so that these two difference images can be fused to obtain an efficient difference image.

3.1 Log ratio difference image

The log ratio difference images for the multi temporal images X_1 and X_2 are obtained using the formulae

$$X_L = |\log X_2 - \log X_1| \quad (1)$$

Log ratio difference image is a simple difference image operator which calculates the log difference between images. The log operation causes the conversion of multiplicative noise in to an addictive one. The log-ratio operator enhances the low-intensity pixels and deteriorates the high intensity pixels; as a result the categorization of the pixels into the changed and the unchanged classes is made more symmetrical. Also the background of the log-ratio image is flat. But the drawback in using the log-ratio operator is that, the information about the changed areas gained from the log-ratio image is not in accordance with real change trends, since the log-operator deteriorates the high intensity pixels.

3.2 Gauss log ratio difference image operator

Inorder to enhance the real change trend as well as suppress the unchanged portions in the difference image and preserve the homogeneity of the changed portions, the Gauss-log ratio operator is used. Gauss log ratio difference image considers the intensities of local patches. Where $X_1'(i, j)$ and $X_2'(i, j)$ are two patches centered at points (i, j) and using this the gauss log ratio operator is calculated as follows

$$X_{1r}(i,j) = \log\left(X_1'(i,j)\right) * G \quad (2)$$

$$X_{2r}(i,j) = \log\left(X_2'(i,j)\right) * G \quad (3)$$

Here G is a rotationally symmetric Gaussian low pass filter with a standard deviation of 0.5, defined as

$$G = \begin{bmatrix} 0.0113 & 0.0838 & 0.0113 \\ 0.0838 & 0.6193 & 0.0838 \\ 0.0113 & 0.0838 & 0.0113 \end{bmatrix}$$

And the difference image is obtained as

$$X_r(i,j) = \sum_{m=-1}^{1} \sum_{n=-1}^{1} \left| X_{1r}(i+m, j+n) \quad - X_{2r}(i+m, j+n) \right| \quad (4)$$

Here G matrix is used to maintain the integrity of the subsequent clustering algorithm.

4. IMAGE FUSION

Image fusion is used to fuse the difference image obtained via log ratio difference image and gauss log ratio difference image operator, so that we can make use of full information of both operators. Image fusion combines the difference image output so that it retains the desirable characteristics of the input image as well as increases the efficiency of the difference image. The basic steps are:

1. Load the images.
2. Merge the two images using Daubenchies wavelet decomposition for 2 levels.

4.1 Image fusion using DWT

The image fusion using DWT is considered because of it is spatially good with less computational complexity. DWT increases the quality and also overcomes the correlation between adjacent scale image information and fully reflects local variation of the original image. The DWT fusion is an earlier method and it lacks shift invariance and have problem of aliasing. So in this paper a recent method such as NSCT is used for fusion as well as for denoising the images, and also NSCT method is compared with the DWT fusion method to analyze the results.

4.2 Image fusion using NSCT

NSCT has the characteristics of multi resolution, localization, directionality, anisotropy, and shift-invariant. It can sufficiently capture the geometrical details of the image and keep the object information and the edge well. Gauss log-ratio operator and mean ratio operator is used to transform multiplicative noise into additive one. In order to make the change map possess more complete edge and contour, it is feasible to use NSCT. NSCT is the nonsubsampled version of contourlet transform (CT) and is having features such as multiresolution, localization, directionality, shift invariance etc. The process of image fusion using is shown in figure 2. The procedure for image fusion using NSCT is similar to DWT fusion and the difference is that, the two level decomposition is performed using NSCT as shown in figure 3 and the use of special NSCT filters for fusing high and low frequencies. For that initially the log ratio and gauss log ratio images are considered. The low frequency bands accurately represents the changed regions from both the log and gauss log ratio image, average operation is done in the low frequency band .For the high frequency band the rule of minimum local energy of the coefficients is chosen, and finally the weighted average is applied on coefficients to get the final fused image.

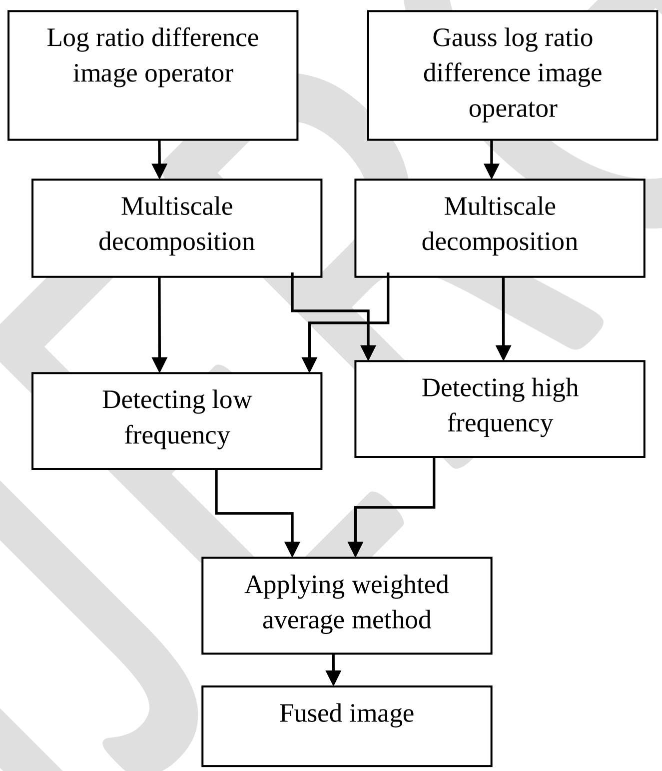


Figure 2: Image fusion using DWT

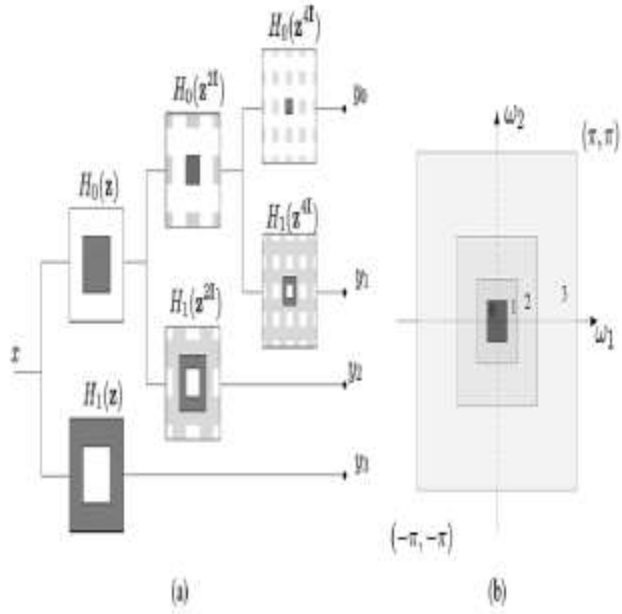


Figure 3: NSCT decomposition (a) 3 stage pyramid decomposition of NSCT. (b) Subbands on the 2-D frequency plane.

5. DENOISING USING NSCT

To reduce the noise of the fused difference image. The main steps are described as follows.

1. Subband images in the different scales and different directions are obtained after the decomposition of the fused difference image, which have the same size as the fused one. The subband images consist of low frequency subbands and high frequency subbands.

2. The coefficients in low-frequency subbands remain unchanged and ones of high-frequency directional subbands at the different scales are suppressed with Donohov threshold.

Donohov threshold is defined as

$$\lambda = \sigma\sqrt{2\log N} \quad (5)$$

Where σ represents noise standard deviation and denotes the sample size. σ is generally unknown, so estimation method is used to determine σ. It is defined as $\sigma = Y_j / 0.6745$, where Y_j denotes the value of coefficient which lies in the intermediate position according to the order of amplitude of high-frequency coefficients of at scale j. When the high-frequency coefficients are larger than the threshold, the coefficients remain unchanged. Otherwise, the coefficients are set to zero. Finally, the denoised difference image X_d is obtained by using inverse NSCT transform. The following figure represents the NSCT decomposition and sub band frame. The lighter gray regions in the figure denote the aliasing caused by upsampling.

6. **K-MEANS CLUSTERING**

The purpose to process the difference image is to discriminate changed area from unchanged area. The difference image obtained by image fusion is sorted out into changed and unchanged area using kernel k-means clustering algorithm. In order to improve the accuracy of the binary change map, the data samples obtained by fusing the log-ratio and gauss log-ratio images are projected to a higher dimensional feature space, in which a linear algorithm can be applied to separate the changed and unchanged pixels. K-means clustering algorithm is applied on the data samples of the fused image in order to perform non-linear clustering. The techniques allows linear evaluation of data in higher dimensional feature space, which results in nonlinear clustering of data samples present in the input space. The higher dimensional feature space is generated by distance measurement applied on the image obtained by fusing the log-ratio and gauss log ratio difference image. Clustering is a nonlinear feature extraction technique. Input is a matrix of similarities, which should be positive semi-definite and symmetric. If two or three features need to be extract use it as a non-linear dimensionality reduction method, otherwise it becomes a nonlinear clustering method. The clustering based on k-means clustering, which is very simple and computationally efficient. The following flow chart represents the k-means clustering algorithm. The NSCT coefficients are extracted from fused image and minimum distance is calculated and coefficients are classified accordingly to generate the change map.

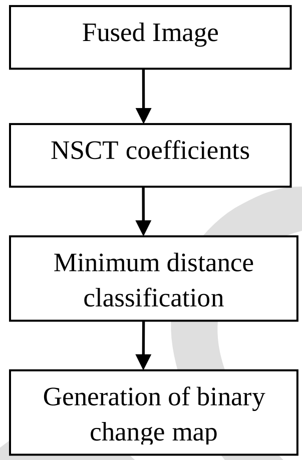
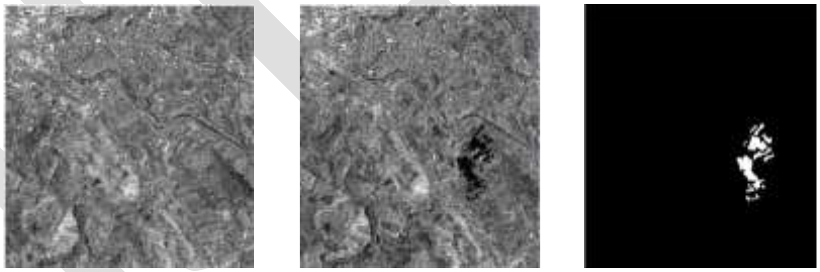


Figure 4: Flow chart for k-means clustering

7. EXPERIMENTAL RESULTS

7.1 Description of the Dataset

The dataset is a portion (512x512 pixels) of two images taken by European Remote Sensing 2 satellite SAR sensor above the region in the vicinity of the city of Bern, Switzerland during April and May, 1999 correspondingly. During this period the river Aare flooded wholly the cities of Thun and Bern, and hence the Aare valley was selected as the test site.

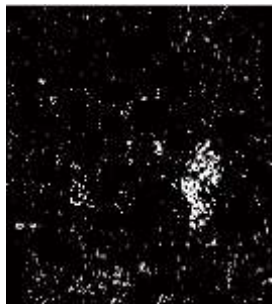


(a) (b) (c)

Figure 5: Multitemporal images for the city of Bern :(a) April, 1999 (b) May, 1999(c) ground truth.

In order to validate the accuracy of the proposed approach quantitatively, the results obtained has been compared with the ground truth for the Bern area. This ground truth was obtained through past information and photo analysis.

7.2 Experimental Results

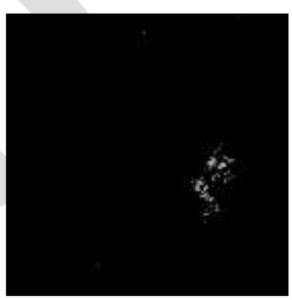
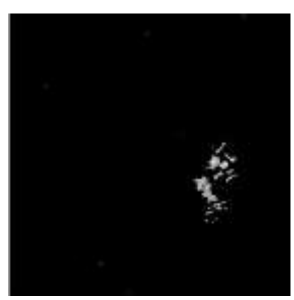



(a) (b)


(c) (d)

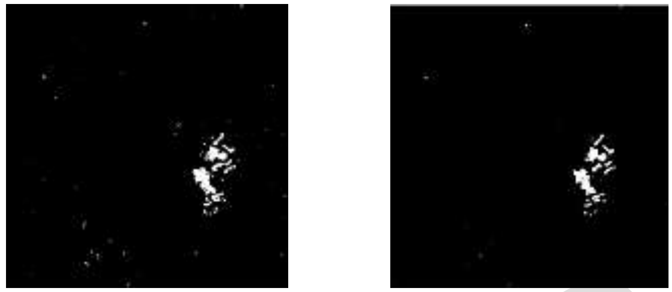
Figure 6: (a) Log ratio difference image (b) gauss log ratio difference image (c) DWT fused image (d) NSCT fused image.

Initially the multi temporal satellite images are loaded and difference images are obtained via log ratio and gauss log ratio operator. The results are shown in figure 6, and then these two images are combined to get the fused image. The fused images are constructed using NSCT. The previous DWT (Discrete Wavelet Transform) technique of fusion is also done to compare results of both the methods. After fusion the images are decomposed using NSCT. The coefficients are extracted using this approach and denoising using Donohov threshold is also performed for the efficient reduction of speckle noise. The denoised NSCT coefficients are shown in figure7. Then the NSCT coefficients are reconstructed and are then subjected for K- means clustering to obtain final change map.

(a) (b)

Figure 7: Image obtained after (a) DWT fusion (b) NSCT fusion



(a) (b)

Figure 8: (a) Change map obtained for 7.a (b) change map obtained for 7.b, using k-means clustering.

Table 1: Result analysis using parameters of the obtained output with ground truth

Parameters	For DWT fusion	For NSCT fusion
Mean	0.3642	0.4574
Standard Deviation	0.2163	0.1746
PSNR (dB)	18.9797	29.6073
Entropy	5.856	7.5362
Structural similarity index(SSIM)	0.9325	0.9545
Feature Mutual Information (fmi)	0.7562	0.8862

Table 1 shows the quantitative analysis of the obtained results. From the table it is clear that the NSCT method of fusion improves the change detection process with an improved PSNR of 29.6073dB and SSIM as 0.9539. Also other quantitative parameters such as mean, variance, entropy, structural and feature mutual information (fmi) are also measured to compare the results. The NSCT method of fusion gives good results with the ground truth data.

8. CONCLUSION

This work mainly focuses on the multi temporal SAR image's change detection and aims for a reliable change map. The techniques for the proposed work involve the techniques such as: difference image operator, image fusion, NSCT (Non Sub-sampled Contourlet Transform) and feature clustering. Efficiency of the change map can be increased by fusing the difference image and by using an advanced clustering algorithm. The concept of change detection of SAR data is likely to extend to the medical field, since the medical field contains a wide variety of applications in medical diagnosis.

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