

# BEMD-based high resolution image fusion for land cover classification: A case study in Guilin

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**ABSTRACT:** Analysis of image texture feature can help to reduce the adverse effects of the condition that same object but different band or same band but different object. Therefore, if it can add and highlight the texture information to the remote sensing image, it will be very helpful in the classification of ground objects. In this paper we consider to add SAR image information in classification. Bidimensional empirical mode decomposition (BEMD) has been widely applied to the analysis of non-stationary and non-linear signals. This paper proposes a new method for fusing high resolution SAR and optical image in Guilin area, based on Bidimensional empirical mode decomposition (BEMD) method.

## 1. Introduction

SAR image contains information such as surface roughness, object shape, orientation, and moisture content pertaining to the target location. Texture information is more stable than spectral characteristics, and therefore holds special significance in the classification of SAR images [1]. Multi-source image data fusion has been shown to be preferable to single image for automated land cover classification.

A number of methods for texture analysis have been developed over the years. However, the textural information extracted by GLCM depends on direction of object features, adjacent distance between two different surface features, and sub-image size. The mean value of Gray characteristic in four directions, at 0°, 45°, 90°, and 135°, is typically used to obtain the final textural features of an image. It has been



shown that an adjacent distance of no greater than  $1/3^{\text{rd}}$  of the size of the small window should be chosen [2]. Thus, determining the window size is the crucial step.

Certain factors—e.g., foreshortening, range and azimuth shift, layover, speckle noise, etc.—make SAR images difficult to interpret [3]. A panchromatic image with high spatial resolution can reflect the edge information of the relevant objects in the image [4]. Combining the characteristics of SAR and panchromatic images can yield a high-quality image that can benefit image processing tasks, such as land cover classification [5]. BEMD has been widely applied to many fields, such as signal detection [6] and noise reduction [7]. Because of its superiority over other decomposition methods in non-stationary and non-linear signal processing, it has been used in multispectral image fusion and panchromatic image fusion [8]. Since the local area characteristics of an image should be represented by pixels that are strongly correlated, an area-based fusion scheme may yield improved fusion results.

## 2. Study area and dataset

### 2.1. Study area

Our chosen area for our experiment is Guilin, a world-renowned tourist destination located in the northeast of Guangxi Zhuang Autonomous Region. It is located between  $24^{\circ}18' \sim 25^{\circ}41'$  north latitude and  $109^{\circ}45' \sim 110^{\circ}40'$  east longitude, with an estimated area of  $2.78 \times 10^4 \text{ km}^2$  (Fig.1).

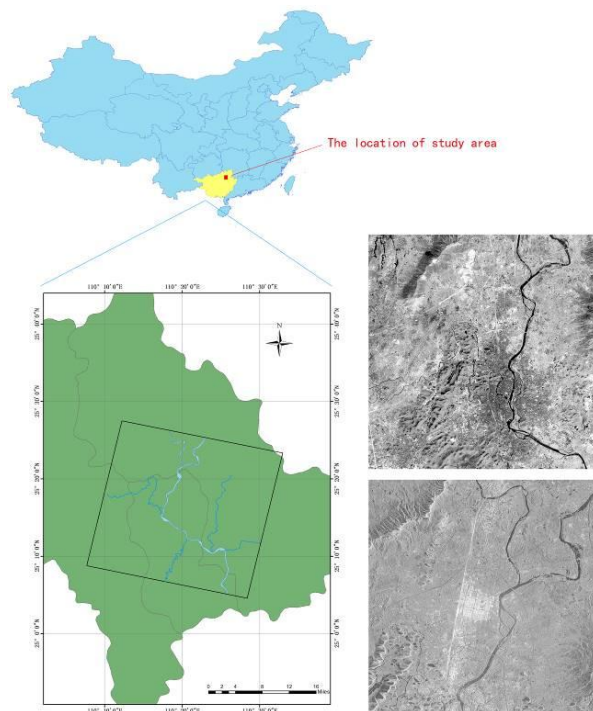


Figure 1. Location of the study area.

### 2.2. Dataset

In our experiments, we used TerraSAR-X images acquired on 14 October 2013, at a spatial resolution of 3m with a single polarisation in the HH mode. The Gaofen-1(GF-1) is a high-resolution Earth observation satellite developed by the Institute of Space Technology at the China Aerospace Science

and Technology Corporation. The GF-1 remote sensing data used in this study consisted of high resolution panchromatic images which acquired on 14 October 2013 at 03:34:40 and the spatial resolution of panchromatic waveband is  $2 \text{ m} \times 2 \text{ m}$ .

### 3. Data Processing

In this section, we explain our work in the following steps: data pre-processing, panchromatic and SAR image fusion, extraction and selection of texture features, and land cover classification.

#### 3.1. Pre-processing

Speckle noise reduction is necessary for SAR images. It can be reduced by multi-look processing or spatial filtering. For SAR image processing, the Lee filter can be expressed as follows:

$$\hat{x}_{\text{Lee}}(i) = \bar{z}(i) + k(i)(z(i) - \bar{z}(i)) \quad (1)$$

where  $\hat{x}_{\text{Lee}}(i)$  denotes the minimum mean square error estimate of pixel  $i$ , and  $z$  and  $x$  represent the SAR image and the speckle-free image, respectively.  $k(i)$  is a weighting function, and can be defined as  $k(i) = \sigma_x^2(i)/\sigma_z^2(i)$ .  $\sigma_x^2(i)$  and  $\sigma_z^2(i)$  represent the local statistics of  $x(i)$  and  $z(i)$ , respectively,  $\bar{z}(i)$  is estimated over a small neighbourhood. The filtered image can preserve the inherent characteristics of the SAR image while minimizing speckle noise.

#### 3.2. The fusion of SAR and panchromatic image based on BEMD

BEMD is an integral transform technique which is highly efficient and adaptive, and can be adapted to analyse on-linear and non-stationary datasets [9]. Through BEMD, any complicated signal can be decomposed into multiple scales of spatial frequencies, called intrinsic mode functions (IMFs). The components are extracted from signals using a sifting algorithm. BEMD picks out the highest remaining frequency oscillation in the signal. This means that each IMF contains components of lower frequency than the preceding one. Considering its superiority, BEMD offers considerable improvement for the result of image fusion. For a given SAR image ( $D^{\text{SAR}}$ ) and a panchromatic image ( $D^{\text{PAN}}$ ), the following steps can be adopted to obtain the fused image based on BEMD[10]:

(1) Decompose images  $D^{\text{SAR}}$  and  $D^{\text{PAN}}$  into modes of frequencies  $\{I_i^{\text{SAR}}, R_i^{\text{SAR}}\} (1 \leq i \leq n)$  and  $\{I_j^{\text{PAN}}, R_j^{\text{PAN}}\} (1 \leq j \leq n)$ , respectively, by using BEMD.  $I$  is the IMF and  $R$  is the residual.

(2) Suppose that  $T(T = \min\{m, n\})$  is the number of the IMFs of each of the SAR and the panchromatic images. The left IMFs ( $m-T$  or  $n-T$ ) of the image are incorporated into the corresponding residual. Then images can be expressed as the sum of the IMFs and the residual as follows:

$$D^{\text{SAR}} = \sum_{k=1}^T I_k^{\text{SAR}} + R_T^{\text{SAR}}, \quad D^{\text{PAN}} = \sum_{k=1}^T I_k^{\text{PAN}} + R_T^{\text{PAN}} (1 \leq k \leq T) \quad (2)$$

(3) Fuse the IMFs  $\{I_k^{\text{SAR}}, I_k^{\text{PAN}}\}$  and residual  $\{R_T^{\text{SAR}}, R_T^{\text{PAN}}\}$  with an adaptive area-based weighting scheme. In order to preserve as much information as possible regarding the SAR and the panchromatic images, we use a weighted algorithm instead of simple replacement. The weights from an adaptive area-based scheme of IMFs and residuals can be calculated as follows: If the window is smooth, the weight of each pixel in the same window can share the same weight. The weight is the average weight of pixels obtained from the pixel-based scheme. Otherwise, the weight from the pixel-based scheme is retained. This step can be represented as

$$\gamma_{\text{area\_based}} = \begin{cases} \overline{\gamma_{\text{pixel\_based}}}, & \text{if the window is smooth} \\ \gamma_{\text{pixel\_based}}, & \text{otherwise} \end{cases}, \quad (3)$$

Once the weight of the  $k$ th IMF, denoted by  $\alpha_k^{\text{SAR}}$ , and the residual of the SAR image,  $\beta_T^{\text{SAR}}$ , are obtained. The fused  $k$ th IMF and the residual can be calculated as follows:

$$I_k^{\text{fuse}} = \alpha_k^{\text{SAR}} I_k^{\text{SAR}} + (1 - \alpha_k^{\text{SAR}}) I_k^{\text{PAN}} \quad (4)$$

$$R_T^{\text{fuse}} = \beta_T^{\text{SAR}} R^{\text{SAR}} + (1 - \beta_T^{\text{SAR}}) R^{\text{PAN}} \quad (5)$$

(4) Obtain the fused image using inverse BEMD:

$$D^{\text{fuse}} = \sum_{k=1}^T I_k^{\text{fuse}} + R_T^{\text{fuse}} \quad (6)$$

### 3.3. Result of fusion of SAR and panchromatic images based on BEMD

Lee filter was chosen for speckle noise reduction in the SAR image. Following registration, the speckle-free SAR image and the panchromatic image were fused using BEMD. To prove the superiority of our proposed fusion method, we compared it with the method based on wavelets. The basis of the wavelets was Daubechies, and their decomposition level was 3 (Fig.2). The details of original images and fusion images obtained using different fusion methods show in Fig.3.

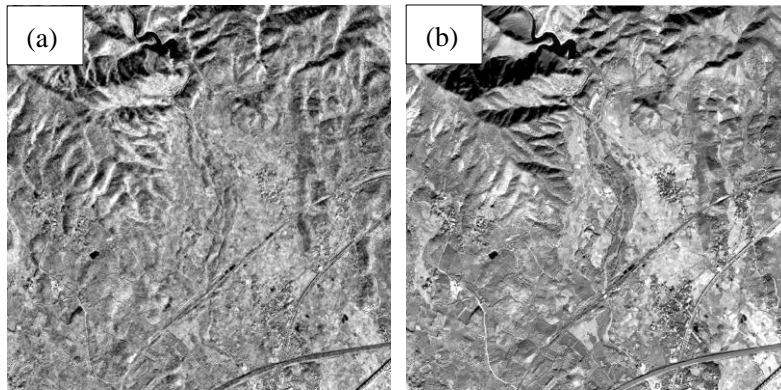


Figure 2. (a) Fusion image based on the BEMD method. (b) Fusion image based on the DWT method.

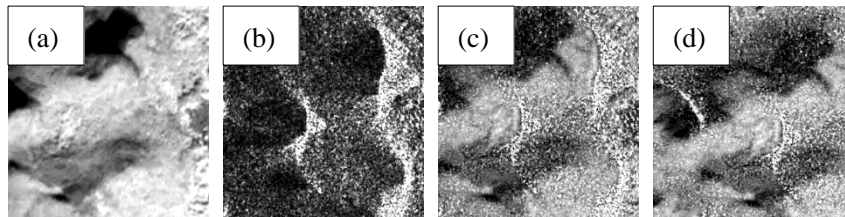


Figure 3. (a) Details of panchromatic image (b) Details of SAR image (c) Details of fusion image by DWT method (d) Details of fusion image by BEMD.

By visual inspection, we can see that the fusion images preserved the character of the SAR image and combined the contour information of the panchromatic image. In order to prove the superiority of our proposed BEMD fusion method, we calculated entropy, spatial frequency, and average gradient to quantitatively analyse the performance of each method. These quantitative indices are listed in Table 1.

Table 1. Evaluation results of fusion methods

Fusion method	Entropy	Average gradient	Spatial frequency
BEMD	7.8818	35.3146	64.4228
Wavelet	7.8825	34.5929	62.9135

According to the definition of entropy, spatial frequency, and average gradient, the larger the values of the indices, the more information a given image contains. From the table, we can see that the entropies of the fused images obtained using the two methods were nearly identical in value, whereas the average gradients and spatial frequencies of the images fused using our BEMD-based method were significantly greater than those of the images obtained using the wavelet-based method. This means that the fusion image obtained using our method contained more useful information.

### 3.4. Result of land cover classification based on fusion image and texture analysis

Along with the six eigenvectors of the BEMD fusion image obtained by GLCM, PCA is employed to reduce their dimensionality. The top two components, which contained the greatest amount of information, were joined with the original image to generate a new image. The new image was divided into four classes—water, building, vegetation, and farmland—using the SVM classifier. Evaluation criteria for classification results, such as overall classification accuracy, mapping accuracy, user's accuracy, and the kappa coefficient, are shown in Table 2.

Table 2. Confusion matrix of classification of BEMD fusion image.

	Building	Water	Vegetation	Farmland	Total	User's accuracy
Building	423	0	1	25	471	95.2%
Water	0	381	0	0	381	100%
Vegetation	0	0	306	70	376	81.4%
Farmland	12	0	44	299	355	84.2%
Total	457	381	351	383	1572	
Producer's Accuracy	97.4%	100%	87.2%	78.1%		

\*Note: Overall accuracy=91% Kappa coefficient=0.8800

We conducted three additional experimental studies to evaluate the classification results based on different texture analysis methods and images. These covered the following cases: (1) A SAR image with texture obtained by adaptive window used for classification; (2) A wavelet-based fusion image with texture obtained by adaptive window used for classification; (3) A BEMD-based fusion image with texture obtained by a window of a certain size used for classification

Table 3 lists the accuracy values of these methods.

Table 3. Classification accuracy values of different approaches.

Classification accuracy	Proposed approach	Case 1	Case 2	Case 3
Overall accuracy	91.0%	86.2%	89.4%	87.7%
Kappa coefficient	0.8800	0.8153	0.8588	0.8359

Our proposed classification approach yielded the best classification accuracy in table 3. According to

these results, we see that the semivariogram can be used to assess the best parameters of the GLCM, and texture features obtained using the adaptive window is useful.

#### 4. Conclusion

In this paper, we proposed an approach for land cover classification involving the fusion of SAR and panchromatic images based on BEMD. An improved GLCM using semivariogram was then used to determine the best parameters for texture analysis and obtain the eigenvectors. Experiments' result showed that our proposed classification approach can improve land cover classification accuracy.

#### 5. Acknowledgements

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