EMD and KPCA-based Speckle Suppression in SAR Images

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Abstract. This paper proposes a speckle suppression method for synthetic aperture radar (SAR) images based on empirical mode decomposition (EMD) and kernel principal component analysis (KPCA) following three steps: first, SAR image after logarithmic transformation is decomposed by EMD; second, noise in each intrinsic mode function (IMF) is further removed by KPCA; finally, the denoised SAR image is obtained by accumulating the IMFs processed by KPCA. In the second step, IMF, decomposed by KPCA, is reconstructed by the selection of appropriate principle components according to noise energy proportion, which is approximately calculated based on the statistical properties of speckle noise and energy distribution model of EMD-decomposed Gaussian white noise (GWN). Experimental results show that, compared with traditional EMD-based image denoising algorithms, the proposed method is superior in both speckle suppression and detail information retention.

1. Introduction

As SAR image can be affected by its own inherent speckle noise, speckle suppression has become a crucial step in SAR image processing, and also the basis for subsequent SAR image feature extraction, segmentation and recognition. While the speckle noise is effectively filtered during the denoising process, it is necessary to keep as much important information as possible on the direction and texture of SAR images. Traditional SAR image speckle suppression algorithms are mainly spatial filtering methods[1, 2] and multi-resolution analysis filtering method based on wavelet transform[3, 4, 5].

The use of EMD in denoising provides a new method for SAR image speckle suppression. According to research results [6, 7, 8], for nonlinear and unsteady signals, EMD decomposition presents a better performance than wavelet decomposition, reflecting the essential characteristics of the information in the signal in a better way. As a result, EMD has been gradually applied to the denoising process of SAR images for a better speckle suppression effect.

When using traditional EMD partial reconstruction method to denoise, much detail information could be lost, and noise is hard to be completely removed, which limits the denoising effect. In this paper, an EMD denoising algorithm based on KPCA is proposed with the aim to improve the denoising performance of EMD on SAR images according to the decomposition characteristics of EMD and KPCA to noise signal. Firstly, noise energy contained in each IMF is calculated approximately based on the noise energy distribution model; then KPCA-decomposed IMF is reconstructed by the selection of appropriate principle components according to noise energy proportion; finally, denoising SAR image is obtained by accumulating IMFs processed by KPCA. Experiments show that compared with traditional partial reconstructed EMD denoising algorithm and EMD denoising algorithm based on wavelet threshold, KPCA-based EMD partial reconstruction denoising algorithm has a better performance both in noise removal and detail retention.
2. Steps Regarding KPCA and EMD-based Speckle Suppression

To remove more noise and ensure better edge retention, a KPCA and EMD-based speckle suppression algorithm is proposed and the overall steps involved are as follows:

1) Calculate edge direction of the SAR image $I(i, j)$ and take $k(x, y) = (a(x \cdot y))^d$ as a kernel function;
2) Employ log transformation and mean adjustment for $I(i, j)$; the processed image is connected as Z-shaped by horizontal, vertical and $\pm 45^\circ$ direction, and is recorded as $\tilde{I}_j(n) \ j = 1, 2, 3, 4$;
3) Denoising for $\tilde{I}_j(n) \ j = 1, 2, 3, 4$ is performed separately in the following ways:
   3.1) Conduct EMD decomposition for $\tilde{I}_j(n)$; suppose IMF is $\{imf_k\}$, and order $\varepsilon(V_1) = \varepsilon(imf_1)$, so $\varepsilon(W_k), k \geq 2$, namely noise energy contained in $imf_k$, is calculated based on formula (15);
   3.2) Order $E = imf_k - E(imf_k), k \geq 2$, and the original SAR image is taken as the training dataset of KPCA;
   3.3) Conduct KPCA decomposition for $\tilde{f}_k$; calculate $H$, or the number of principal components that should be retained when denoising in feature space based on formula (21); calculate the denoising result in feature space by formula (17); calculate the original image $\tilde{f}_k'$ by iteration;
   3.4) $imf'_k = \tilde{f}'_k + E(imf_k)$ is the result for $imf_k$ after denoising; the logarithmic image $\frac{\tilde{I}_j'}{j}$ after denoising is obtained by accumulation of processed IMFs.
4) Based on edge information, data of the final denoising image is selected from $I'_j$ which is obtained by exponential transformation of $\tilde{I}_j$.

3. Experiment Results and Analysis

To get objective evaluation on speckle suppression effect, the paper conducts analysis based on three aspects:

(1) The equivalent number of ENL: $ENL = \frac{A u^2}{\sigma^2}$ indicates the smoothness of the image

   After denoising, the larger the ENL value, the higher the smoothness and the better the noise suppression effect. $u$ and $\sigma$ respectively represents the mean and standard deviation of the homogeneous region of the image.

(2) The mean ratio MR reflects the degree to which the radiation features of the original image is maintained after denoising, and the closer the mean ratio is to 1, the more the radiation characteristics are kept.

(3) The standard deviation STD reflects the dispersion degree between the pixel grayscale value and the grayscale mean of the image. As the intensity of the speckle noise decreases after speckle suppression, STD of the image will be reduced.
Figure 1. Speckle suppression results of different methods

Figure 1 is the SAR image of Ku spectrum with a resolution of 2m and a rich edge and texture detail information. In the experiment, the algorithm proposed in this paper is compared with EMD-CPR, the conventional EMD partial reconstruction, and EMD-CIIT, the clear iterative EMD Interval-thresholding in terms of speckle suppression performance. In EMD-CPR denoising, choose the IMF devoid of noise while in the EMD-CIIT denoising, the denoising result is selected according to edge information. In the method proposed in this paper, the kernel function is $k(x, y) = (a(x \cdot y) + b)^d$ with $a = 2, b = 0, d = 3$. To compare the speckle suppression smoothing effect of the three algorithms, the homogeneous region in the rectangular frame domain in the test image is selected as the test data to calculate the equivalent number of looks (ENL), and MR and STD are calculated for the whole SAR image. The experimental results of different algorithms are demonstrated by Figure 1 (b) ~ (d), and the parameters of denoising performance are shown in Table 1.
Table 1. Experiment Results

|                | Original SAR | EMD-CPR  | EMD-CIIT | The proposed method |
|----------------|--------------|----------|----------|---------------------|
| ENL            | 11.189       | 78.978   | 95.285   | 116.790             |
| MR             | 1.000        | 1.061    | 1.055    | 1.047               |
| STD            | 38.424       | 28.923   | 28.215   | 27.687              |

From the visual effect of the experimental results, the EMD-CPR filter can smooth the speckle noise well, but because of the direct abandonment of the noise item of the IMF and direct reconstruction with the remaining IMFs, so some details are lost, resulting in blurring image details and some noise left after denoising. Compared with EMD-CPR, the EMD-CIIT filtering method based on wavelet threshold is improved in denoising effect and detail maintenance, but because the partial coefficient of IMF is removed by wavelet threshold, part of the detail information is still lost, so the image after denoising emerges as jitter at some edges. For the image denoised by the proposed method, the overall image is clear, with the speckle well suppressed and the edges, point target and line target better maintained. Besides, the proposed method produces a better visual effect compared with the other two algorithms.

From the numerical results of Table 1, ENL of each denoised image has been greatly improved, showing that the three methods have good inhibition effect on speckle noise. ENL of homogeneous region after denoised by the proposed method is maximized, which indicates that the speckle capacity of the proposed method is improved to a certain extent compared with the other two methods. In terms of MR of the denoised images, each of them is close to the ideal value of 1, indicating that the three methods can effectively maintain the radiation characteristics of the original image. Moreover, compared with the other two methods, the ability to maintain the radiation characteristics of the proposed method is also improved, with MR decreasing by 0.067 compared with EMD-CPR and by 0.032 compared with EMD-CIIT. The three denoising methods share a similar STD, which is significantly smaller than that of the original image, reflecting an outstanding filtering effect.

Through the above analysis, it’s inferred whether from the visual subjective evaluation, or through objective evaluation indicators for quantitative evaluation, the method proposed in this paper is superior compared with traditional EMD speckle suppression algorithms.

4. Conclusion

In the traditional EMD partial reconstruction SAR image denoising algorithm, the noise-dominant IMF is completely discarded, and the remaining signal-dominated IMFs are reconstructed directly without processing, which results in a loss of detail information in SAR images after denoising, and noise cannot be completely removed. In order to overcome this, based on the traditional partial reconstruction algorithm, a EMD and KPCA-based speckle suppression algorithm is proposed. Firstly, noise energy contained in each IMF of the EMD-decomposed logarithmic SAR image is calculated. Secondly, IMF is decomposed by KPCA; a certain amount of principal component components are removed according to the proportion of noise energy in each IMF, so that the energy of the removed component is approximately the same as the noise energy in the IMF; then IMF is reconstructed with the remaining components. Third, cumulative reconstruction of each $\text{imf}_{k}$, $k \geq 2$ processed by KPCA is carried out to achieve final denoising of the SAR image. Simulation results show that the proposed method is better than the traditional EMD partial reconstruction denoising algorithm and wavelet threshold EMD denoising algorithm in both speckle suppression and detail information retention.

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6. References

[1] M. N. Sumaiya, R. Shantha Selva Kumari. SAR image despeckling using heavy-tailed Burr distribution[J]. Signal, Image and Video Processing, 2017, 11(1).

[2] Ting Lu, Shutao Li, Leyuan Fang, Jón Atli Benediktsson. SAR Image Despeckling Via Structural Sparse Representation[J]. Sensing and Imaging, 2016, 17(1).

[3] Jian Ji, Xiao Li, Shuang-Xing Xu, Huan Liu, Jing-Jing Huang. SAR Image Despeckling by Sparse Reconstruction Based on Shearlets[J]. Acta Automatica Sinica, 2015, 41(8).

[4] Xuezhi Yang, Kewei Wu, Yiming Tang. A new metric for measuring structure-preserving capability of despeckling of SAR images[J]. ISPRS Journal of Photogrammetry and Remote Sensing, 2014, 94.

[5] MuraliMohanBabu. Y, Subramanyam. M.V, GiriPrasad. M.N. A Modified BM3D Algorithm for SAR Image Despeckling[J]. Procedia Computer Science, 2015, 70.

[6] Nithin Raj, R. Sethunadh, P. R. Aparna. Object detection in SAR image based on bandlet transform[J]. Journal of Visual Communication and Image Representation, 2016, 40.

[7] Farzana, E., Bhuiyan, M.I.H.. Despeckling SAR images with an adaptive bilateral filter[P]., 2013.

[8] Zhao Hongyu, Wang Quan, Wu Weiwei, Wang Qingping, Yuan Naichang. SAR image despeckling based on improved non-local means algorithm[P]. Electromagnetics in Advanced Applications (ICEAA), 2014 International Conference on, 2014.