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# An algorithm for multi-sensor image fusion using maximum a posteriori and nonsubsampled contourlet transform☆

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ABSTRACT

Multi-sensor image fusion draws an inference based on the information obtained from different sensors. Recently, wavelet and contourlet transforms have been widely used in multi-sensor image fusion. But these transforms have been inadequate in the representation of images due to their subsampling. Hence, a fusion algorithm based on Synthetic Aperture Radar (SAR) and Panchromatic (PAN) images in Nonsubsampled Contourlet Transform (NSCT) domain is proposed. NSCT gives flexible multiscale, multidirectional expansion for images. A high fusion accuracy is achieved by 'Maximum A Posteriori (MAP)' estimation based on Rayleigh and Laplacian probabilities for despeckling of SAR higher frequency coefficients. Subsequently, the despeckled SAR coefficient is directly fused with PAN coefficients using the newly developed Edge-based fusion rule. The combination of NSCT, MAP and Edge-fusion rule facilitates maximum preservation of the edge and the texture information. The performance of the proposed fusion algorithm is evaluated using reference and non-reference quality metrics. The results prove that the proposed method outperforms the existing NSCT methods by preserving maximum features.



## 1. Introduction

Satellite image fusion has been widely used for addressing issues in observing the earth through satellite images. Image fusion integrates single or multiple image modalities (multisensory images) for improving the feature quality. Reflected features like urban, forest, land, water and mountain areas are highly elevated and sensitive to environmental changes, resulting in distortion of remotely sensed images. A fusion of different sensor images helps in predicting the real feature properties and aids in interpretation, competence and accurate analysis of features.

The geometric shapes, structure and hidden features such as underwater level, air moisture and soil properties, are sensed by Synthetic Aperture Radar (SAR) throughout day and night, in any weather condition. Radiometric images with speckle noise are produced by SAR sensor under microwave radiation. Speckle noise degrades the acquired SAR image. Each pixel is spread with the coherent summation of the scattered signal from the target as well as the signal from the ground [1]. Despeckling leads to loss of information. The sensitivity to environmental issues such as light radiation, clouds, and air moisture is the main drawback in optical images. Accurate spatial information without noise degradation is captured by a high-resolution Panchromatic (PAN) sensor [2]. Therefore, a fusion of SAR and PAN images is important to preserve and present all the spatial and radiometric information using image fusion techniques.

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Researchers have explored, several SAR image fusion methods based on spatial and transform domains like Brovey [3], Principal Component Analysis (PCA) [4], Intensity-Hue-Saturation (IHS) [5] and Improved Intensity-Hue-Saturation (IIHS) [6]. Spatial domain techniques directly manipulate the image pixels to achieve desired fusion result. However, spatial domain methods produce spatial distortion in the fused image [7]. Due to the distortion in the fused image, further feature extraction and analysis are affected. To avoid this difficulty, frequency domain approaches like Fourier transforms and multi-resolution analysis are used [8,9]. Frequency domain techniques transfer the spatial domain image to the frequency domain, and all the frequency information are then fused to give more feature information. Multi-resolution analysis is a more powerful technique than the Fourier transform method, due to localization of time-frequency.

Wavelet [10], curvelet [11], ripplet [12], etc. are powerful multi-resolution fusion techniques to maintain the spatial quality of the fused image when compared to the other fusion methods. Wavelet transform methods are very effective in SAR image fusion. Wavelet transform makes use of two separate one-dimensional wavelet transform for the two-dimensional surfaces represented by the rows and columns respectively. Due to this, wavelet transform restricts the directional filtering on the image surface. Contourlet transform provides multidimensional and multiscale analysis, which is more reliable in image representation. Thus contourlet based SAR image fusion offers good preservation of features when compared to wavelet based SAR image fusion [13]. However, contourlet transform is shift-variant, and results in information loss during fusion. So, Nonsubsampled Contourlet Transform (NSCT) is widely used in many applications like medical, electrical, etc. [14–20].

SAR image fusion results are affected by other factors such as fusion rules and speckle noise. Fusion rules are important in getting the desired results in the fusion process. There are three types of fusion rules: pixel-level, feature-level and decision-level [21]. The selection of fusion rules depends entirely on the need of the user. While fusing the SAR images with other sensor images, the SAR image contains more accurate information, but is speckled. In the existing SAR image fusion methods, speckle noise is not dealt or despeckled before the fusion process [22,23]. Radiometric artifacts are created during the fusion with speckled SAR images. The speckle gives the wrong interpretation of the pixels. On the other hand, fusion with despeckled SAR images has a chance for loss of information. Fused SAR images contain radiometric information with detailed edge and texture features. So, an accurate despeckling of SAR is needed, before the fusion process.

To avoid these inconveniences during fusion of SAR image, this work proposes an algorithm, that combines SAR despeckling and fusion process. SAR and PAN images are processed in the NSCT domain. NSCT gives multi-dimension and multi-scaling expansion of images with shift-invariant [24], an accurate representation of SAR and PAN image coefficients. To avoid the loss of information due to despeckling, the statistical prior distribution and Bayesian MAP estimator for higher frequency SAR coefficients are proposed, since higher frequencies contain enriched information. The outcome of the SAR coefficient from the Bayesian MAP estimator is fused with the PAN coefficients. Two different pixel based fusion rules namely Maximum Edge Strength (MES) and Maximum Magnitude (MM) for lower and higher frequency coefficients are used to increase feature preservation in the SAR and PAN images. To evaluate the performance of the proposed method, different reference and non-reference quality metrics are calculated and compared with the existing SAR image fusion methods. The major novelties of the proposed fusion are:

1. NSCT processed SAR and PAN coefficients.
2. MAP derived speckle free SAR coefficient is directly fused with the PAN coefficients.
3. An edge-based fusion rule is proposed for fusion of higher frequency coefficients of SAR and PAN images.

Section 2 explains the proposed fusion method. Section 3 gives the details of the fusion rules. Section 4 discusses the different quality metrics. Section 5 provides the experimental results and Section 6 concludes the work.

## 2. Proposed work

To achieve maximum preservation of features from the SAR and PAN images, a combination of NSCT and MAP techniques is used. Due to speckle noise, SAR image fusion is not achieved easily. MAP estimation using prior distribution shrinks speckle noise without loss of information. The despeckled SAR image is then fused with PAN coefficients. Firstly, NSCT is performed on the registered SAR and PAN images to get higher (Hi) and lower (Li) frequency coefficients. Then, the MAP estimator is created based on the Rayleigh (R) and Laplacian (L) statistical priors [25]. R and L distributions are used for modeling the noise and noise-free SAR-NSCT higher frequency coefficients respectively. RL prior models help to statistically examine the texture of the coefficients to remove noisy pixels. Therefore, variance needs to be well defined in the SAR images. The Rayleigh and Laplacian prior probabilities are more appropriate to define the variance of the SAR image. The aspects of variance, Rayleigh, and Laplacian prior probabilities are explained as follows:

Rayleigh model (prior for multiplicative noisy variance)

SAR images are recorded as complex images and most often viewed as magnitude images. The amplitude or background statistics of the SAR image is Rayleigh distributed. Thereby noise variance is accurately described by the Rayleigh probability distribution [26]. The Rayleigh model is given in Eq. (1).

$$P_R(R) = \frac{R}{\alpha^2} \exp\left(\frac{-R^2}{2\alpha^2}\right), \quad (1)$$

Where $R$ is the amplitude of the noise or random variable and $\alpha$ is the fading parameter.

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