Research on Algorithms of SAR and Optical Image Fusion

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ABSTRACT

With the rapid development of multi-source remote sensing technology, the application of Multi-source image fusion has increased. SAR and optical images have their own characteristics, quite different from each other. In order to avoid the excessive extraction of SAR image feature information and reduce the spectral distortion. In this paper, aims at the problem of excessive extraction in SAR image feature extraction based on gray level gradient algorithm. A fusion method combine adaptive HIS with phase congruency method is proposed. The phase congruency algorithm can distinguish the target contour and texture edge using phase information, it can effectively avoid the excessive extraction of the edge, and the adaptive HIS algorithm can overcome two image gray value differences, to achieve a smooth transition to the information, reduce the spectral distortion of the image fusion. Experimental result shows that the proposed method can effectively inject the missing features into optical image as well as better to maintain spectral and spatial structure quality, achieve a better visual effect, and improve the capability of target detection.

KEYWORDS

SAR Image, Optical Image, Image Fusion, Phase Congruency, HIS.

INTRODUCTION

In 1952, the first SAR system was successfully developed and confirmed by the non-coherent radar experiment at the University of Illinois[1], and the first SAR image was acquired in 1953[2]. Since then, the United States has successively developed and launched several SAR satellites, in 1981. On November 12th, the "Colombia" mechanical SAR-A took off and successfully acquired a SAR image with surface penetration capability[3], which has aroused widespread concern in the international remote sensing community. Many countries have successively carried out research on spaceborne SAR. At the same time, SAR and multi-source image fusion have also received much attention. In 1992, in order to obtain more image information[4], the US Department of Defense established a fusion group to develop dozens of military fusion
systems. In addition, developed countries such as Japan and the European Union have also implemented data integration plans in some major research projects, and have successively launched some practical operating systems.

At present, there are various methods in the field of SAR image and visible image fusion[5, 6]. From the implementation process analysis of these methods, it can be decomposed into two steps: the extraction of spatial structure and feature information and the injection of spatial structure and feature information[7].

In recent years, HIS-based image fusion methods have gradually become a hot topic in the field of SAR image fusion. The HIS transform method can well add the spatial structure and feature information of the SAR image to the visible light image, but it has the phenomenon of spectral distortion caused by the addition. At present, there are many feature addition methods that overcome severe spectral distortion. For example, based on the method of luminance component modulation, the texture feature of the SAR image is extracted by using the ratio of the SAR image after filtering to the low-pass approximation image pixel value, and is used to modulate the luminance component of the multi-spectral image added to the panchromatic image spatial information, thereby avoiding the SAR image. The addition of spatial structure information has the purpose of reducing spectral distortion[8]; Hong et al.[9] combined the characteristics of panchromatic and SAR images to establish feature selection criteria to adjust the luminance component of multi-spectral images to avoid over-addition. Happened. Although such a method based on brightness modulation can effectively overcome the over-addition phenomenon of the traditional HIS method, it is unavoidable to lose some structural information in the SAR image, and it is necessary to make up for the details of the full-color image. Spectral adaptive HIS method is applied to multi-spectral and panchromatic image fusion. This method has good spectral preservation for IKONOS images, but it is not suitable for other remote sensing images[10]; an adaptive HIS method is adaptive. Linear combination coefficients are used to obtain spatial structure information of high-resolution images and added to low-resolution images[11, 12]; HIS methods based on wavelet and empirical decomposition models use wavelet to extract features of SAR images, and empirically decompose model injection features[13]. This kind of method can better inject the spatial structure and feature information of SAR image into visible light image. However, due to the large difference of imaging band range between the two images, the added spatial structure and feature information cannot be smoothed with the surrounding information of the original visible light image. Transition, causing spectral distortion.

In this paper, an adaptive HIS image fusion algorithm for phase consistency feature preservation is proposed. The spatial information is extracted from the SAR image by phase consistency. The lack of texture edge information and the SAR image phase information based on the luminance gradient information are fully considered. The importance of extracting SAR image information is better. At the same time, in order to reduce the spectral distortion of the fused image, the luminance component of the visible image is as close as possible to the SAR image, and a smooth transition of the added features is realized. Finally, the phase feature information is selected according to the phase feature information. The spatial structure information and the inverse HIS transform are added to obtain the final fused image. Experiments were carried out to select SAR and visible light images with feature information, and the two experiments of filtering and unfiltering were compared with traditional HIS, PCA,
wavelet and NSCT fusion algorithms. The subjective, objective and feature recognition rates were compared with the proposed algorithm.

METHODOLOGY

PHASE CONSISTENCY ALGORITHM

In 1981, Oppenheim et al. synthesized two new images by exchanging the phase and amplitude information of the two images, and found that the composite image retaining the original image phase information and adding the amplitude information of the new image still has the characteristic contour of the image, while retaining the amplitude of the original image. The composite image in which the information is added to the phase information of the new image is disorganized\cite{14}, and it is concluded that the phase information can represent the feature information of the entire image. Later, during the research on the Mach band, Morrone\cite{15} found that the phase information and the human visual perception system have similar sensitivity to image features, further confirming the advantage of using phase information to extract image feature information.

The phase consistency algorithm does not select the feature information of the image based on the luminance gradient information, but assumes that the feature points of the image appear at the maximum phase of the image Fourier component. Figure 2.1 shows the Fourier expansion of square wave and triangle wave. It can be found that the Fourier expansion of the square wave signal is consistent with the phase of all sine waves at the same point. Similarly, the Fourier expansion of the triangular wave is at Maximum phase consistency is achieved. When converted to the spatial domain, the characteristic points of the square wave signal appear in the two step feature points of the square wave, corresponding to the sum of the frequency domains, indicating that the characteristic information of the signal appears in the place with the largest phase consistency. The Fourier series of the arbitrary waveform thus defined are as follows:

\[
 s(x) = \sum_{n=0}^{\infty} \frac{1}{(2n+1)^p} \sin[(2n+1)x + \phi]
\]

(1)

Where \( \phi \) is the initial phase, which \( P \) is the amplitude gain factor.
The step characteristic information of the square wave signal and the triangular wave signal is similar to the sharply changing pixels in the remote sensing image. These sharply varying pixels constitute image texture information in the image, so the phase consistency algorithm can detect the texture of the image. If the phase consistency response of a certain pixel value of the image is high, it indicates that the pixel is a texture feature point of the image, and the phase consistency information of the image is obtained by traversing the entire image.

**ADAPTIVE HIS ALGORITHM BASED ON PHASE CONSISTENCY FEATURE PRESERVATION**

The visible light image contains rich spectral information and the SAR image is lacking. The fusion of the two images needs to preserve the spectral information of the original visible light image as much as possible. The adaptive HIS algorithm can separate the spectral information from the luminance information, and overcome the visual inconsistency caused by the weak correlation between the gray values of the two images. For the SAR image characteristics, the phase consistency algorithm extracts the SAR image feature information. Combined with the adaptive coefficient adjustment HIS and phase consistency feature retention algorithm, the ideal fusion image is approximated from both spatial and spectral aspects. The steps of the fusion algorithm are as follows:

1. Image preprocessing: mainly includes SAR image denoising, two image registration and visible image upsampling to the same resolution as SAR images.
(2) Extraction of feature information: The local frequency information \( P \) of the SAR image is calculated by orthogonal Logarithmic Gabor[16] filter banks of different spatial frequencies.

Because of the singularity of the logarithmic function at the origin, it is impossible to construct the Log Gabor function in the spatial domain, go to the frequency space design filter, and then perform the inverse Fourier transform. At each point of the image signal, a set of response vectors is obtained, while the filter at one scale also gets a vector. The real part is obtained by convolving the dual symmetric filter convolution, and the imaginary symmetric filter is convolved to obtain the imaginary part. The final phase consistency is:

\[
P \sum A_p(x, y) = \sqrt{F^2(x, y) + H^2(x, y)}
\]  

(2)

(3) Injection of feature information: The adaptive HIS algorithm is used to adjust the gray correlation between SAR and visible image. The weighting factor \( P \) is introduced in the feature part of SAR image, and the spatial information of the original SAR image is screened to obtain the final fused image. for:

\[
F = \sum_{i=1}^{N} \left[ V_i + P(S - I) \right]
\]  

(3)

Here is the final fused image, which is the RGB three bands of the visible light image after registration, which is the phase consistency weight of the SAR image, and is the component processed by the adaptive HIS algorithm. The flow chart is as follows:

Figure 2. Sketch map of adaptive HIS with Phase Congruency Method.
EXPERIMENTAL RESULTS AND ANALYSIS

EXPERIMENTAL DATA AND PARAMETER SETTINGS

In order to verify the effectiveness of the proposed algorithm in feature recognition and improve visual interpretation, multi-group SAR and visible image fusion are carried out. It is investigated that the Sentinel C-band radar satellite can penetrate water body imaging, and the experimental resolution is 5m. The image of the Tianjin suburb and the Bohai port photographed by the Sentinel One satellite, the Landsat8 Tianjin suburb image with a resolution of 30m and the Bohai port image of the high score of the 16m resolution in the same period. Among them, the 4, 3, 2 band synthetic true color image of Landsat8 data is selected, and the sentinel No. 1 data selects VH polarization mode, which has strong penetrability. The pre-experiment data pre-processing includes: orthorectification and image registration to ensure that the offset error of the corresponding pixel of the image to be fused is less than 0.5 pixels, and each set of visible light data has the same spatial resolution as the SAR image. Figure 1 and Figure 2 show three satellite images, respectively.

![GF-1 Optical image](image1) ![Sentinel I SAR image](image2)

Figure 3. Data of GF-1 and Sentinel-1 satellite.

This chapter uses two sets of experiments to verify the effectiveness of the algorithm. In the first experiment, the ESA Sentinel No. 1 C-band radar satellite image was selected, which can penetrate the water body imaging with a resolution of 5 meters covering the Tianjin Bohai area. The data is SAR-BM3D filtering proposed by Parrilli et al. in 2012; landsat8 is used as the visible light image. The resolution is 30 meters for fusion. In the second experiment, the PMS image with high resolution of 8 meters in China is selected as the visible light image and merged with the sentinel No. 1 C-band radar satellite image. The SAR image is not filtered.

The two experimental images were registered with ENVI 5.1 and sampled to the same resolution. HIS[17] and PCA[18] algorithms are representative of linear combination approximation methods; wavelet[19] transform uses haar wavelet base, 2 scale decomposition, NSCT[20] transform scale decomposition filter and directional filter respectively use filters and filters as representative of spatial filtering approximation method Subjective and objective evaluation with the algorithm of this chapter.
EVALUATION

Due to the lack of visible light image with high spatial resolution as the reference image, combined with the purpose of SAR and visible light image fusion, according to Wald's evaluation index, the visible light image completed by registration sampling is used as a reference. Correlation coefficient (CC) and root mean square error (RMSE) are used to calculate the spectral information of the fused image. It can be seen from the analysis in the article that there is spatial structure information of the interfering object interpretation in the SAR image, so the spatial details of the fused image are compared. There are certain drawbacks. In order to verify the comprehensive performance of each algorithm in both space and spectrum, this paper uses the general
image quality index (UIQI) and the relative dimensionless total error (ERGAS) to compare the overall performance of the fused image.

| TABLE I. EVALUATION RESULTS OF EACH ALGORITHM IN FIGURE 3.2. |
|-----------------------------------------------------------|
| **CC** | 1  | 0.721 | 0.731 | 0.435 | 0.779 | 0.977 |
| **RMSE** | 0  | 11.38 | 10.25 | 31.87 | 9.473 | 2.507 |
| **UIQI** | 1  | 0.713 | 0.691 | 0.483 | 0.716 | 0.741 |
| **ERGAS** | 0  | 9.954 | 9.673 | 27.85 | 8.288 | 2.187 |

In the experiment, the Sentinel 1 SAR image without filtering is merged with the high score 1 data. Figure 3.2(a)~(d) shows that the corresponding algorithm cannot suppress the speckle noise. The fused image is richer than the original visible image. Spatial structure information, but severely affected by noise is not conducive to the interpretation of the ground object, and there is spectral distortion. For example, in Figure 3.1(b), the speckle noise in the lower right water area is more obvious, and the fused images Figure 3.2(a)~(d) still contain severe speckle noise. However, it can be seen from Figure 3.2(e) that the algorithm proposed in this chapter has strong ability to maintain structural information and spectral information while effectively suppressing speckle noise.

CONCLUSION

This paper evaluates both the subjective and objective aspects of the traditional algorithm and the proposed algorithm by using multiple sets of remote sensing images of Landsat8, Gaofen-1 and Sentinel-1 satellites. At the same time, combining the purpose and significance of SAR and visible image fusion, the proposed image is based on the image. The evaluation method of interpretation and feature recognition accuracy rate verifies the effectiveness of the proposed algorithm.

The innovations of this paper have the following two aspects: Firstly, in view of the shortcomings of SAR image gray value in extracting spatial information, it is proposed to use phase information to make up, and adjust the gray correlation of the two images, so that the fused image has good Visual effects. Secondly, using reverse thinking, the information of the fused image is obtained from each pixel of the original image, and the evaluation indexes of the constructed fused image are excellent.

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