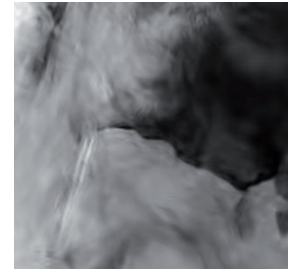


Satellite image enhancement: systematic approach for denoising and resolution enhancement

Mejora de la imagen de satélite: enfoque sistemático para reducción de ruido y mejora de resolución



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RESUMEN

- Este artículo propone un sistema de mejora de imagen de satélite mediante reducción de ruido y mejora de resolución. La técnica en primer lugar descompone el ruido de entrada de imagen en distintas sub-bandas usando la transformada Dual Tree Complex Wavelet y elimina el ruido de estas sub-bandas mediante la función Local Adaptive Bivariate Shrinkage. A continuación, la imagen sin ruido una vez más se descompone en las distintas sub-bandas de frecuencia mediante la transformada Discrete Wavelet. Las sub-bandas interpoladas de alta frecuencia y la imagen sin ruido se utiliza para obtener la imagen súper resuelto aplicando DWT inversa. Los aspectos cuantitativos y cualitativos de los resultados experimentales muestran la superioridad del método propuesto sobre las técnicas convencionales y de vanguardia.
- Palabras clave:** supresión de ruido en imagen de satélite, mejora de la resolución de imagen de satélite, transformada wavelet doble árbol compleja, bivariado encogimiento, transformada wavelet discreta.

ABSTRACT

This paper proposes a satellite image enhancement system consisting of denoising and resolution enhancement. The technique firstly decomposes the noisy input image into different frequency subbands by using Dual Tree Complex Wavelet transform and denoises these subbands by using Local Adaptive Bivariate Shrinkage Function. Then the denoised image once more is decomposed into the different frequency subbands by using Discrete Wavelet Transform. Interpolated high frequency subbands and the denoised image are used to obtain the super resolved image by applying Inverse DWT. The quantitative and qualitative experimental results are showing the superiority of the proposed method over the conventional and the state-of-the-art techniques.

Key Words: Satellite image denoising, satellite image resolution enhancement, dual tree complex wavelet transform, bivariate shrinkage, discrete wavelet transform.

1. INTRODUCTION

These days, various applications such as astronomy, geosciences studies, and meteorology use Satellite images. There are various quality factors in satellite images. Two of the most important ones are noise and resolution issues. When a satellite image is be-

ing captured there are some noise added to the images and these noises have different sources, such as noises added during the data transmission from the capturing station to the research centers, or noises added by the image acquisition tools [1]. Interpretation of a noisy image is difficult for human observers. Such a noisy image needs to be denoised. Furthermore, the noisy images sent by satellites cannot be directly processed. A pre-processing stage is needed whereas image denoising is one of these pre-processing stages. The aim of image denoising is to remove the noise while keeping significant features of the image [2]. Besides, resolution of an image has been an issue in many image and video processing applications, such as video resolution enhancement [3], feature extraction [4], and satellite image resolution enhancement [5].

Interpolation in image processing is a method to increase the number of pixels in a digital image and is widely used in many image processing applications such as real-time actuator positioning [6], multiple description coding [7], and super resolution [8-10]. There are three well-known interpolation techniques, namely nearest neighbour, bilinear and bicubic. Bicubic interpolation is more sophisticated than the other two techniques and produces smoother edges.

Wavelets are also playing significant role in many image processing applications. The two-dimensional wavelet decomposition of an image is performed by applying the one-dimensional DWT along the rows of the image first, and then the results are decomposed along the columns. This operation results in four decomposed subband images referred to the approximate band (LL), vertical band (LH), horizontal band (HL), and diagonal detail band (HH). The frequency components of those subbands cover the full frequency spectrum of the original image.

Image resolution enhancement by using wavelets is a relatively new subject and recently many new algorithms have been proposed [11-14]. Carey et al. [15] have attempted to estimate the unknown details of wavelet coefficients in an effort to improve the sharpness of the reconstructed images. Their estimation was carried out by investigating the evolution of wavelet transform extrema among the same type of subbands. Edges identified by an edge detection algorithm in lower frequency subbands were used to prepare a model for estimating edges in higher frequency subbands and only the coefficients with significant values were estimated as the evolution of the wavelet coefficients. Another wavelet based image super resolution technique is Wavelet Domain Zero Padding and Cycle-Spinning (WZP and CS) [14]. This method adopts the cycle-spinning methodology in the wavelet domain

[14]. There are more state-of-the-art techniques which are using Dual Tree Complex Wavelet Transform (DT-CWT), Stationary Wavelet Transform (SWT), and also Discrete Wavelet Transform (DWT) [16–18].

A popular image denoising method is Local Adaptive Bivariate Shrinkage Function (LA-BSF) which requires priori knowledge of noise and marginal variances [19–21]. This method uses non-Gaussian bivariate distributions and benefits from the dependencies between the wavelet coefficients and their parents. It is reported that the models exploiting the dependency between wavelet coefficients give better results than the ones using an independence assumption [20]. The performance is improved by estimating model parameters in a local neighbourhood. Satisfactory image denoising results have been obtained using DT-CWT based LA-BSF in [20–21].

The DT-CWT has been developed by N. G. Kingsbury [22–24] in order to overcome the disadvantages of classical DWT (i.e. lack of shift-invariance and poor directional selectivity). The DT-CWT uses specially designed real filters in order to provide the desired characteristics of the transform (i.e. approximately shift-invariance, good directional selectivity (for two or more dimensions), perfect reconstruction, limited redundancy, 2:1 for 1-D (2^m for m -D), efficient computation, only twice the simple DWT for 1-D (2^m times for m -D)) [24]. A one level DT-CWT decomposition results in two parallel trees (real and imaginary). The DT-CWT has the advantages of approximately shift-invariance and good directional selectivity (for two or more dimensions) over the classical DWT which are essential for many signal processing applications [22, 24].

In this work, we have proposed a two-stage satellite image enhancement system in which the noisy low resolution input satellite image is firstly being denoised and then super resolved. At the first stage the noisy input image is decomposed into complex noisy subbands using DT-CWT and then the noisy detail (high frequency) subband coefficients are denoised using LA-BSF algorithm. The results of proposed method are compared with several the state-of-the-art techniques; namely, Gaussian filter followed by WZP, WZP and CS, and DWT, LA-BSF followed by WZP, and WZP and CS. The remainder of this paper is organized as follows. A detailed overview of the proposed method is presented in Section 2. Section 3 contains the outcome of experimental results. Finally, Section 4 concludes the paper.

2. THE PROPOSED SATELLITE IMAGE ENHANCEMENT SYSTEM

There are two significant parts of the proposed system, namely, denoising and resolution enhancement. Firstly, the noisy image is decomposed into subbands by using six-level DT-CWT. A one level 2D DT-CWT results in two complex valued low frequency subband coefficients and six complex valued high frequency subband coefficients oriented at $+75^\circ$, $+45^\circ$, $+15^\circ$, -15° , -45° , and -75° [24]. The DT-CWT uses specially designed real filters which are different at the first-level and remaining levels of the transform. In this paper, (9,7)-tap Antonini biorthogonal filter set is used at first-level and 6-tap Q-shift dual filters are used at the remaining levels of the DT-CWT [23]. The reason for using the DT-CWT in the denoising algorithm is that it has the properties of approximately shift-invariance and good directional selectivity lacking in the classical DWT. These properties are essential for many signal processing applications including denoising [22, 24].

These noisy subband coefficients are denoised using LA-BSF algorithm [19–21]. The LA-BSF requires prior knowledge of the

noise variance σ_n^2 and marginal variance σ^2 for each wavelet coefficient. In the denoising algorithm the marginal variance for the k^{th} coefficient is estimated using neighbouring coefficients in a region $N(k)$. Where $N(k)$ is defined as all the coefficients within a square shaped window that is centered at k^{th} coefficient. The LA-BSF is applied to the magnitude of complex coefficients since the real and imaginary parts are not shift invariant. It is assumed that the images are corrupted by the Gaussian noise. A 7×7 window size $N(k)$ is used for the best denoising results [20].

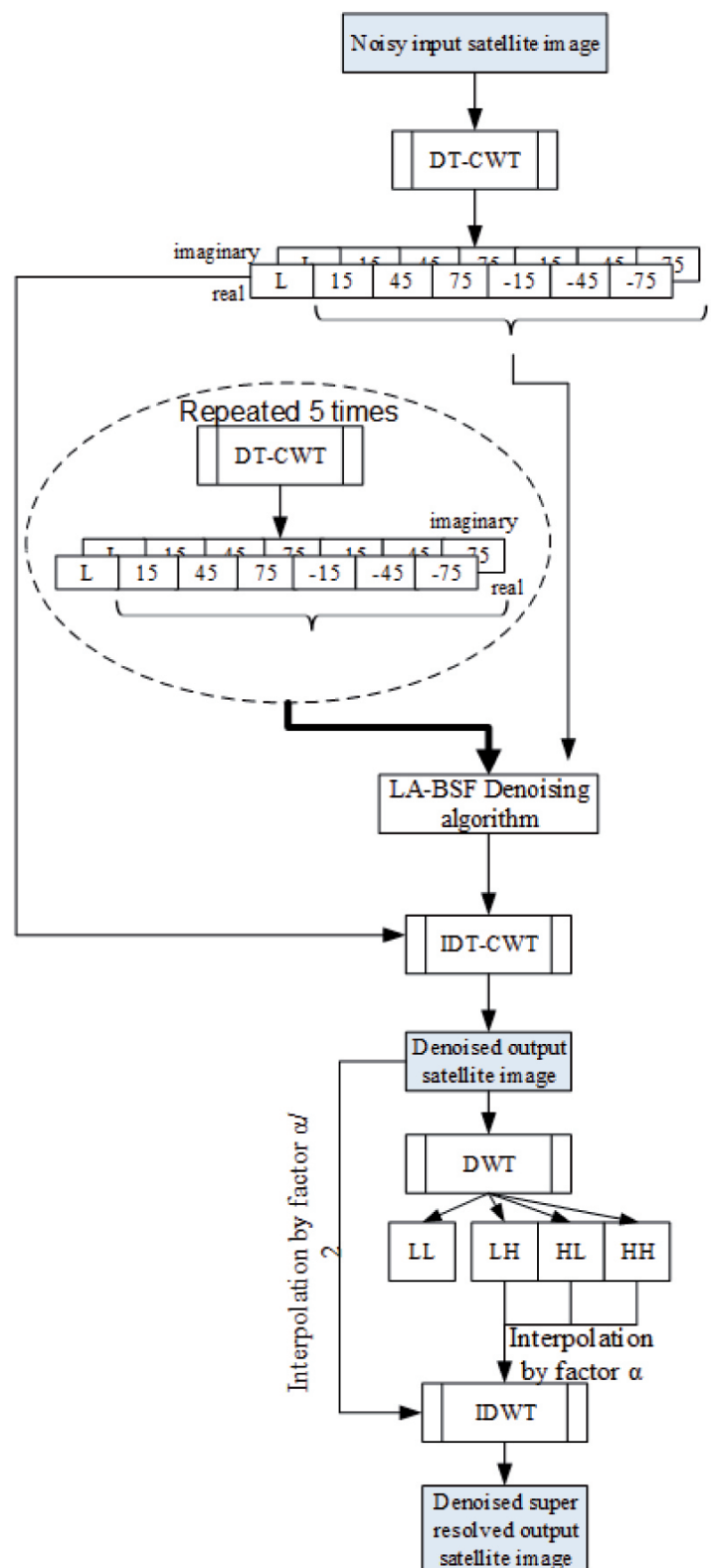


Fig. 1: The proposed satellite image enhancement system consisting of denoising followed by resolution enhancement

Method	PSNR (dB) of enhanced image	
	Fig. 2	Fig. 3
Gaussian filter + WZP ($\sigma=15$)	28.04	26.07
Gaussian filter + WZP ($\sigma=25$)	23.67	22.59
LA-BSF + WZP ($\sigma=15$)	28.26	26.78
LA-BSF + WZP ($\sigma=25$)	23.08	23.33
Gaussian filter +(WZP and CS) ($\sigma=15$)	29.11	27.48
Gaussian filter +(WZP and CS) ($\sigma=25$)	24.97	24.25
LA-BSF + (WZP and CS) ($\sigma=15$)	31.49	30.11
LA-BSF + (WZP and CS) ($\sigma=25$)	25.15	25.89
Gaussian filter + DWT ($\sigma=15$)	30.03	29.92
Gaussian filter + DWT ($\sigma=25$)	25.45	26.01
Proposed Technique ($\sigma=15$)	33.09	31.78
Proposed Technique ($\sigma=25$)	30.82	28.74

Table 1: Objective test (PSNR) results of proposed image enhancement system (denoising and resolution enhancement)

The main loss of an image after being super resolved by applying interpolation is on its high frequency components (i.e. edges), which is due to the smoothing caused by interpolation. Hence, in order to increase the quality of the super resolved image, preserving the edges is essential. As it was mentioned, in this work, discrete wavelet transform (DWT) [25] has been employed in order to preserve the high frequency components of the image.

In the resolution enhancement stage, DWT is used to decompose an input image into subband images. LH, HL, and HH subband images contain the high frequency components of the input satellite image. In resolution enhancement step the bicubic interpolation is applied to high frequency subband images. Here, instead of using LL, which contains less information than input image, we are using the input satellite image for re-sampling by interpolation which increases the quality of the super resolved image. By interpolating input satellite image and high frequency subbands and then by applying inverse DWT (IDWT), the output image will contain sharper edges than the interpolated image obtained by re-sampling of the satellite image directly. This is due to the fact that, the interpolation of isolated high frequency components in HH, HL and LH will preserve more high frequency components after

the interpolation of the respective subbands separately than interpolating the satellite image directly.

In all steps of the proposed noisy satellite image resolution enhancement technique db.9/7 wavelet as mother wavelet function and bicubic interpolation as interpolation technique have been used. Fig. 1 shows the proposed satellite image enhancement system.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Fig. 2 and 3 (a) illustrate low resolution images taken from several aerospace and geosciences resources mentioned in the acknowledgment section. We assume that Gaussian white noise (GWN) of zero mean and standard deviation (STD) $\sigma=25$ is added to the images as shown in (b). The denoised images via DT-CWT based LA-BSF algorithm are given in (c). Then, the denoised images are super resolved by using WZP (d) and DWT (proposed) (e). Table 1 is showing the quantitative comparison between the proposed satellite image enhancement and the state-of-the art techniques such as Gaussian filter + WZP, Gaussian filter + WZP and CS, Gaussian filter + DWT, LA-BSF + WZP, and LA-BSF + WZP and CS. The quantitative test results and visual qualities of final results indicate that the proposed technique achieves sharper images than the ones achieved by direct interpolation and WZP.

4. CONCLUSIONS

In this paper, a new satellite image enhancement system including denoising and resolution enhancement was proposed. The

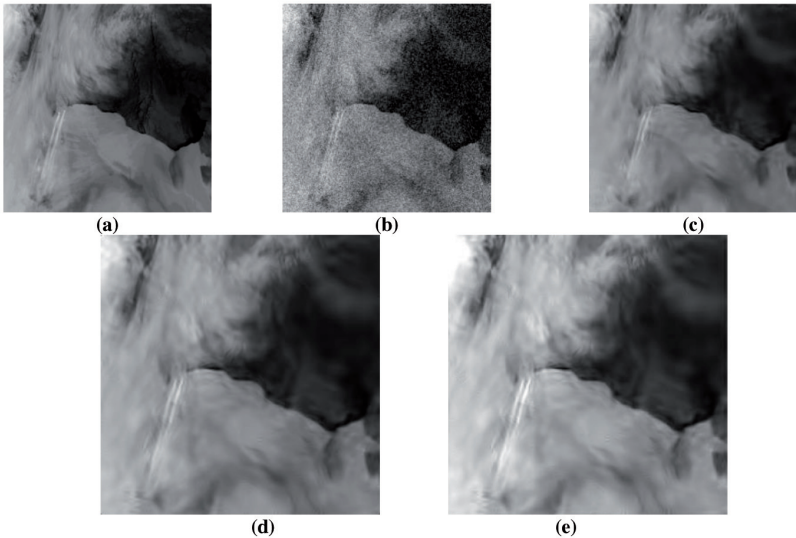


Fig. 2: Original low contrast image from Antarctic Meteorological Research Centre (a), the noisy image (b), denoised image using DT-CWT based LA-BSF algorithm (c), resolved images (after denoising) by using: WZP (d), and DWT technique (e)

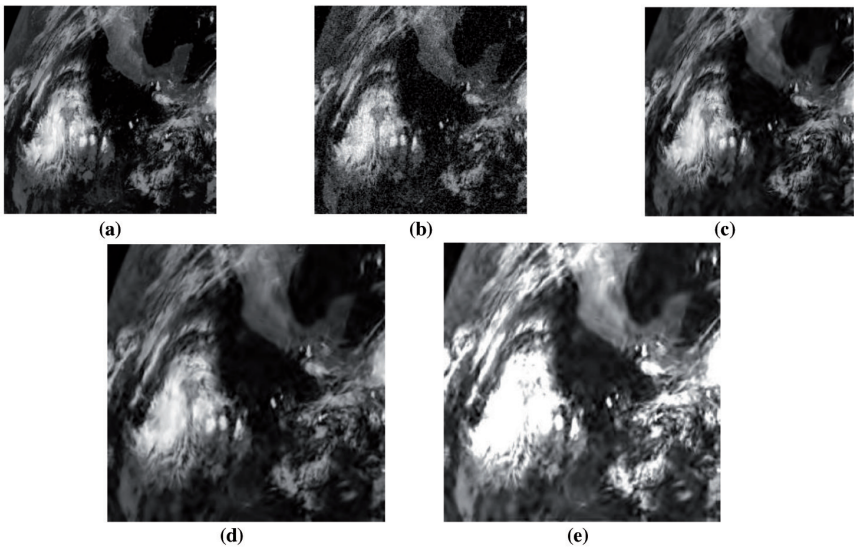


Fig. 3: Original low contrast image from Antarctic Meteorological Research Centre (a), the noisy image (b), denoised image using DT-CWT based LA-BSF algorithm (c), resolved images (after denoising) by using: WZP (d), and DWT technique (e)

proposed technique decomposed the noisy input image into various frequency subbands by using DT-CWT. After removing the noise by applying LA-BSF technique, its resolution was enhanced by employing DWT and interpolation of high frequency subband images. An original image was interpolated with half of the interpolation factor used for interpolating the high frequency subband images and the super resolved image was reconstructed by using IDWT. The proposed technique was compared with various conventional and the state-of-the-art techniques and the quantitative test (PSNR) results and visual results on the final image quality show the superiority of the proposed technique over those techniques.

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