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Enhancement of Satellite Images Resolution Using Dual-Tree Complex Wavelet Transform

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Abstract: Resolution enhancement(RE)methods that are independent of wavelets(interpolation methods) leads to blurring as high frequency components are lost.RE scheme based on Discrete wavelet transform(DWT) produces artifacts due to shift variant property.A complex wavelet-domain image resolution enhancement algorithm based on interpolation of the high-frequency subband images obtained by dual-tree complex wavelet transform (DT-CWT) is proposed.In this scheme, decomposition of the low resolution image into different subbands is done followed by the interpolation of the high frequency sub band images and the input image.This method uses forward and inverse dual-tree complex wavelet transform (DT-CWT) to generate the high-resolution (HR) image from the given low-resolution (LR) satellite input image. The HR image is reconstructed from the LR image by combining all these interpolated images using the inverse dual-tree complex wavelet transform (IDT-CWT). The quantitative peak signal-to-noise ratio (PSNR) and results are presented to reveal the superiority of the proposed technique through comparisons between state-of-the-art resolution enhancement methods.

Keywords: Resolution enhancement, image interpolation,shift variant, dual-tree complex wavelet transform, discrete wavelet transform, satellite image.

I. INTRODUCTION

Resolution of an image is an important consideration in all image and video processing applications like satellite image resolution enhancement,video resolution enhancement and feature extraction.Satellite images are used in many applications like astronomy,geoscientific studies and geographical information systems. Resolution enhancement of images is a preprocess that is to be used for many satellite image processing applications such as vehicle recognition, building recognition, and bridge recognition.

Image resolution enhancement methods can be categorized into two major classes namely

1)Spatial domain; and 2) Frequency-domain.

The term spatial domain refers to the image plane itself and approaches in this category are based on direct manipulation of pixels in an image.Frequency domain processing techniques use many transformations such as to achieve a high resolution image.

Interpolation has been used for resolution enhancement in image processing widely[2],[3]. There are four well known interpolation techniques, namely nearest neighbour, bilinear, bi-cubic and Lanczos interpolation methods. Nearest-neighbor method is a simple method of multivariate interpolation in one or more dimensions. The nearest neighbor algorithm selects the value of the nearest point and does not consider the values of neighboring points at all, yielding a piecewise-constant interpolant.This method results in edge distortion.

Bilinear interpolation considers the closest 2x2 neighborhood of known pixel values surrounding the unknown pixel's location. It performs a weighted average of these 4 pixels to arrive at its final interpolated value. Bilinear interpolation however produce a greater number of interpolation artifacts such as aliasing, blurring and edge halos. Bi-cubic interpolation also considers the 16 pixels around it (for a total of 4x4 pixels) while computing an average. Images re-sampled with bi-cubic interpolation are smoother and have fewer interpolation artifacts compared to bilinear interpolation.The Lanczos interpolation which is a windowed form of sinc filter is better than other interpolation methods because it has the increased ability to detect edges and linear features.It offers good results by showing reduction in blurring,aliasing etc [4]. Resolution enhancement schemes which are not based on wavelets suffer from the drawback of losing high-frequency contents leading in blurrness of the image.But Wavelet transform however tend to retain these high frequency components because these transforms provide time and frequency representation simultaneously.Hence resolution enhancement using wavelet transforms is preferable.Hence wavelet transforms like Discrete Transform(DWT) and Stationary Wavelet Transform(SWT) were used for

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resolution enhancement. A discrete wavelet transform (DWT) is any wavelet transform for which the wavelets are discretely sampled. In DWT-based resolution scheme , a common assumption that the low-resolution (LR) image is the low-pass filtered subband of the wavelet-transformed high-resolution (HR) image. This requires that wavelets coefficients in subbands shold be estimated with high-pass spatial frequency information in order to estimate the HR image from the LRimage.These DWT-based resolution enhancement schemes in [5] generate artifacts (due to DWT shift-variant property). The Stationary wavelet transform (SWT) is a wavelet transform algorithm designed to overcome the lack of translation-invariance of the discrete wavelet transform (DWT). Translation-invariance is achieved by removing the down-samplers and up-samplers in the DWT and up-sampling the filter coefficients by a factor of 2(j − 1) in the jth level of the algorithm[6]. To overcome the artifacts produced by these conventional resolution enhancement schemes a new complex wavelet domain resolution algorithm has been proposed.

DT-CWT is shift invariant and tends to have improved directional resolution compared to DWT. It also has limited redundancy.These properties make DT-CWT coefficients inherently interpolable.Hence these features make DT-CWT to be a better approach for image resolution enhancement.This method uses forward and inverse dual-tree complex wavelet transform (DT-CWT) to generate a high-resolution (HR) image from the given low-resolution (LR) satellite input image. The HR image is reconstructed from the LR image together with a set of wavelet coefficients using the inverse dual-tree complex wavelet transform (IDT-CWT).

II. INTRODUCTION TO DUAL-TREE COMPLEX WAVELET TRANSFORM

The complex wavelet transform (CWT) is a complex-valued extension to the standard discrete wavelet transform (DWT). It is a two-dimensional wavelet transform which provides multi resolution, sparse representation, and useful characterization of the structure of an image. Further, it purveys a high degree of shift-invariance in its magnitude. However, a drawback to this transform is that it is exhibits (where d is the dimension of the signal being transformed) redundancy compared to a separable DWT.

A dual tree complex wavelet transform(DT-CWT) is equal to two real valued Discrete wavelet transform(DWT) as shown in Fig. 1.As it is shift invariant it yields perfect directional resolution and aids perfect reconstruction of the satellite image.The Dual-tree complex wavelet transform (DTCWT) calculates the complex transform of a signal using two separate DWT decompositions (tree a and tree b). If the filters used in one are specifically designed different from those in the other it is possible for one DWT to produce the real coefficients and the other the imaginary.

This redundancy of two provides extra information for analysis but at the expense of extra computational power. It also provides approximate shift-invariance (unlike the DWT) yet still allows perfect reconstruction of the signal.

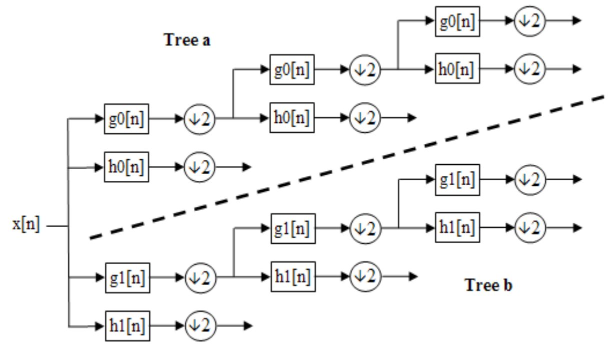

Fig. 1. Block diagram of 3-level DT-CWT

The design of filters is particularly important for the transform to occur correctly and the necessary characteristics are:

- The low-pass filters used in the two trees must differ by half a sample period.
- Reconstruction filters are used for the reverse of Analysis.
- All filters are taken from the same orthonormal set
- Tree a filters and tree b filters are reverse to Eachother.
- The frequency response of both the trees are same.

III. PROPOSED SYSTEM

In the proposed method of resolution enhancement shown in Fig. 2 an input image is decomposed into different subband images by using DT-CWT and the interpolation is applied to the high-frequency subband images. Low-frequency subband images are obtained due to the low resolution of the original image.Hence instead of using low-frequency subband images,which contain less information than the original input image,the input image is used for the interpolation of two low-frequency subband images which ultimately increases the quality of the super resolved image.

e

Fig. 2. Block diagram of the DT-CWT-RE algorithm

The input image is interpolated with interpolation factor of α/2 which is used to interpolate high frequency sub bands.Interpolation of the low resolution input image and the shifted version of the input image in horizontal and vertical directions form the two real valued images.These images

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form real and imaginary components of the interpolated complex LL image, respectively, for the inversr DT-CWT operation. Interpolation of the input image by α/2 and the high-frequency subband images by α is done finally followed by IDT-CWT to get output image.The output image will have sharper edges than the interpolated image obtained by interpolation of the input image directly. This enhanced edges are produced because of the fact that the interpolation of the isolated high-frequency components in the high-frequency subband images will tend to preserve more high-frequency components after the interpolation of the respective subbands separately far better than interpolating the input image directly.

This proposed technique not only interpolates the input image but also the high-frequency subband images obtained through DT-CWT process. As a result a final high-resolution output image is generated by using the IDT-CWT of the interpolated subband images and the original input image.The interpolation method applied is same for all subband and the input images respectively.The performance metrics like Mean square error(MSE),Peak signal to noise ratio(PSNR) are analysed.

The PSNR calculates the peak signal-to-noise ratio, between two images in decibels. This ratio is used as a quality measurement between the original and a reconstructed image. If PSNR value is high, quality of the reconstructed image will be be good.

The MSE represents the cumulative squared error between the reconstructed and the original image, and PSNR represents a measure of the peak error. The low value of MSE leads to low value of error. To compute PSNR the MSE is first calculated using the following equation:

$$MSE = \frac{\sum_{M,N}\left[I_1(m,n) - I_2(m,n)\right]^2}{M * N}$$

where the number of rows and columns in the input image are represented by M,N respectively.

PSNR can be calculated as follows

$$PSNR = 10\log_{10}\left(\frac{R^2}{MSE}\right)$$

where R is the maximum fluctuation in input image. For a 8-bit image, value of R is 255.Thus the Mean Square Error (MSE) and the Peak Signal to Noise Ratio (PSNR) are the two error metrics used to compare image reconstruction quality.

IV. RESULTS AND DISCUSSION

This section presents the results obtained for the proposed DT-CWT resolution enhancement scheme.Inorder to reveal the effectiveness of the proposed scheme over the conventional and state-of-the-art image resolution enhancement techniques, different LR optical images obtained from the Satellite Imaging Corporation webpage [1] were tested.The image of Washington DC ADS40 Orthorectified Digital Aerial Photography is taken for comparison with existing RE techniques such as DWT and SWT.Fig. 3 shows the original "Washington DC" image, the downsampled input image, and the images obtained using SWT-RE , DWT-RE and the DT-CWT-RE schemes.

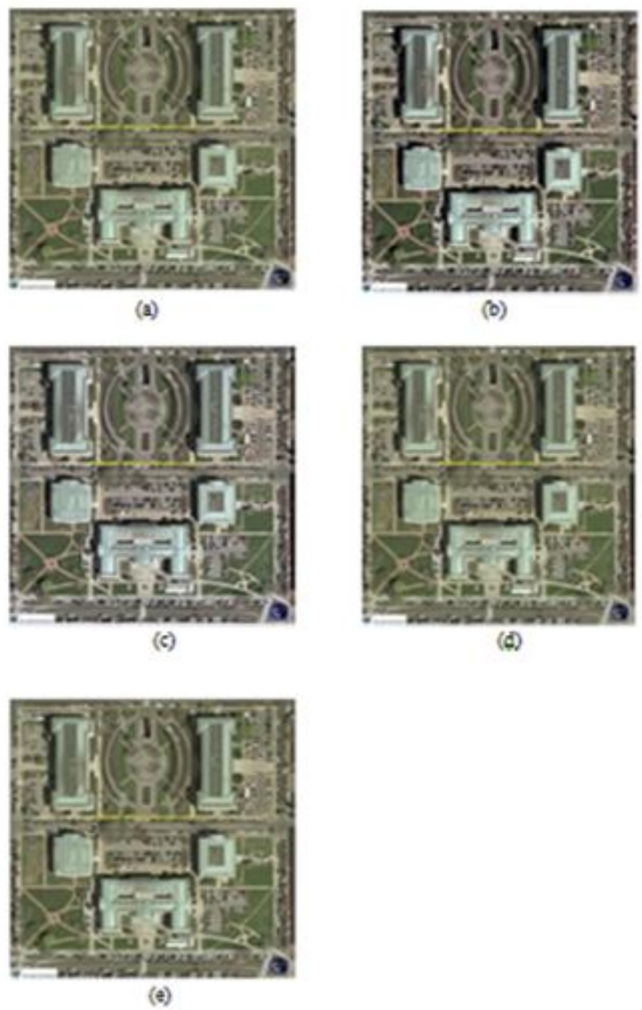

Fig. 3 (a)original "Washington DC" image (b)Input image (c)SWT-RE (d)DWT-RE (e)DT-CWT-RE

The low resolution input image when subjected to SWT splits the image into different sub-bands and these sub-bands will have the same size as that of input image.The HR image reconstructed from these sub-bands is shown in Fig.

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3(c).When the LR image is subjected to DWT decomposes the image into many subbands.The high frequency sub-bands and input LR image are interpolated and combined using inverse DWT to get the HR image as shown in Fig. 3(d).

Finally the HR image reconstructed using DT-CWT is shown in Fig. 3(e) which contains information about the high frequency details such as edges more clearly than any other RE method.

TABLE I shows the PSNR comparisons of the proposed technique(DT-CWT) over the conventional resolution enhancement schemes like DWT,SWT.

TABLE I
COMPARISON OF PSNR OF VARIOUS RE SCHEMES

Technique used	**PSNR**
SWT-RE	10.33
DWT-RE	11.74
Proposed DT-CWT	24.06

TABLE I shows that the Proposed DT-CWT has higher PSNR compared to the conventional schemes SWT-RE and DWT-RE. This is due to the fact that DT-CWT preserves the high frequency details in many directions contributing to the sharper edges.

V. CONCLUSION

A scheme for image resolution enhancement from a single low-resolution image using the dual-tree complex wavelet transform has been proosed. It uses DT-CWT to decompose an image into different subband images, and then the high-frequency subband images are interpolated.High frequency sub band images are interpolated and half of this interpolation factor is used for the input image.All of these interpolated images are combined using inverse DT-CWT to get a super resolved image. The proposed technique is compared with the conventional RE schemes.The PSNR and visual results shows superiority of the proposed scheme over the conventional RE schemes.

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