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RESEARCH ARTICLE

RESOLUTION ENHANCEMENT OF SATELLITE IMAGES USING DUAL-TREE COMPLEX WAVELET AND CURVELET TRANSFORM

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Abstract— ***Resolution enhancement(RE) methods that are independent of wavelets i.e. interpolation methods leads to blurring as high frequency components are lost.RE scheme based on Discrete wavelet transform(DWT) leads to artifacts due to shift variant property. A complex wavelet-domain image resolution enhancement algorithm based on dual-tree complex wavelet transform (DT-CWT) with non local means(NLM) and curvelet transform is proposed. In this scheme, the low resolution image is undergone curvelet transform for denoising. The high frequency sub bands obtained by DT-CWT of the resultant denoised image are interpolated using Lanczos interpolator. The high frequency sub bands are further passed through an NLM filter to cater for the artifacts generated by DT-CWT.The low resolution input image and the filtered high frequency sub bands are combined using inverse DT-CWT to obtain a resolution-enhanced image. 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,curvelet transform, Lanczos interpolation, discrete wavelet transform, satellite image

I. INTRODUCTION

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

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Interpolation has been used commonly for resolution enhancement in image processing widely[2],[3]. There are four well known interpolation techniques, namely nearest neighbour interpolation, bilinear interpolation, bi-cubic interpolation and Lanczos interpolation.

A simple method of multivariate interpolation in one or more dimensions is nearest-neighbor interpolation. The nearest neighbor method 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 computed location. It then takes 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 considers the 16 pixels around it (4x4 pixels) while computing an average. Images re-sampled with bi-cubic interpolation become smoother and have fewer interpolation artifacts compared to bilinear interpolation. The Lanczos interpolation which is a windowed form of sinc filter is better than the 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 that are not based on wavelets suffer from the drawback of losing high-frequency contents leading in blurred image. But Wavelet transform retain these high frequency components because these transforms provide time and frequency representation simultaneously. Hence resolution enhancement using wavelet transforms is most preferable. Hence wavelet transforms like Discrete Transform(DWT) and Stationary Wavelet Transform(SWT) were used for resolution enhancement. A discrete wavelet transform (DWT) is any wavelet transform for which the wavelets are discretely sampled. The two dimensional DWT implementation decomposes image into three detailed sub-images (LH, HL and HH) corresponding to three different directional orientations (vertical, horizontal and diagonal) and lower resolution sub-image LL. The sub-image LL is now a parent image and further is decomposed into four child images for multilevel wavelet analysis. 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 should 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 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].

The conventional DWT is very sensitive to shifts in the input signal; it has poor directional selectivity and also lacks the phase information due to real valued coefficients. To overcome the limitations by these conventional resolution enhancement schemes a new complex wavelet domain resolution algorithm(DT_CWT) 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. Here a DT-CWT and curvelet based nonlocal-means RE technique is proposed using the DT-CWT, curvelet transform, Lanczos interpolation, and NLM.

II. INTRODUCTION TO DUAL-TREE COMPLEX WAVELET TRANSFORM,CURVELET TRANSFORM & NON LOCAL MEANS

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.

These CWTs employ two conventional DWT filter bank trees working in parallel such that respective filters of both the trees are in approximate quadrature. As it is shift invariant it has improved directionality and leads to 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.

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

- The low-pass filters in the two trees must differ by half a sample period
- Reconstruction filters are the reverse of analysis
- All filters from the same orthonormal set

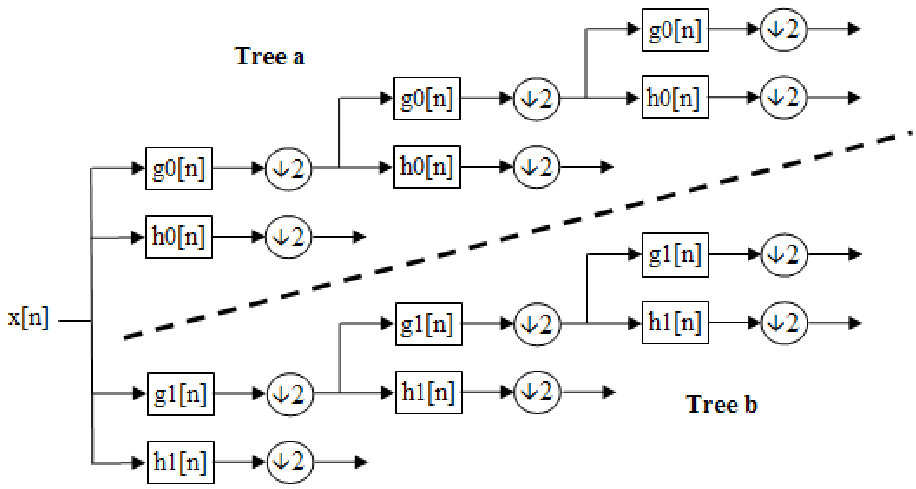


Figure 1 Block diagram of 3-level DT-CWT

- Tree a filters are the reverse of tree b filters
- Both trees have the same frequency response

Most natural images/signals exhibit line-like edges, i.e., discontinuities across curves (so-called line or curve singularities). Although applications of wavelets have become increasingly popular in scientific and engineering fields, traditional wavelets perform well only at representing point singularities, since they ignore the geometric properties of structures and do not exploit the regularity of edges. Therefore, wavelet-based compression, denoising, or structure extraction become computationally inefficient for geometric features with line and surface singularities.

Curvelets are a non-adaptive technique for multi-scale object representation. Curvelets are an appropriate basis for representing images (or other functions) which are smooth apart from singularities along smooth curves, where the curves have bounded curvature, i.e. where objects in the image have a minimum length scale. A curvelet transform differs from other directional wavelet transforms in that the degree of localisation in orientation varies with scale. In particular, fine-scale basis functions are long ridges; the shape of the basic functions at scale j is 2^{-j} by $2^{-j/2}$ so the fine-scale bases are skinny ridges with a precisely determined orientation.

The NLM filter (an extension of neighborhood filtering algorithms) is based on the assumption that image content is likely to repeat itself within some neighborhood (in the image) and in neighboring frames. Non-local means filter is an algorithm used particularly for image denoising. Unlike other local smoothing filters, non-local means filter averages all observed pixels to recover a single pixel. The weight of each pixel depends on the distance between its intensity grey level vector and that of the target pixel.

III. PROPOSED SYSTEM

A complex wavelet-domain approach based on dual-tree complex wavelet transform (DT-CWT) with non local means(NLM) and curvelet transform for image resolution enhancement is proposed.

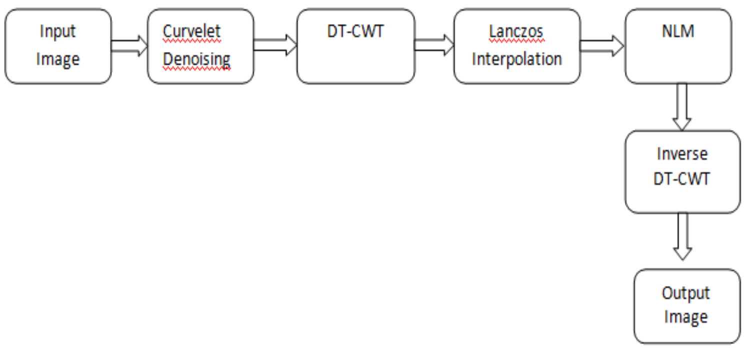


Figure 2 Block diagram of the proposed algorithm

In the proposed algorithm the LR input image is undergone curvelet denoising. The resultant input image is decomposed into different subbands (i.e., C_i and W_i^j, where i ∈ {A,B,C,D} and j ∈ {1, 2, 3}) by using DT-CWT. C_i values are the image coefficient subbands, and W_i^j are the wavelet coefficient subbands. DT-CWT decomposition is done in three levels. The subscripts A, B, C, and D represent the coefficients at the even-row and even-column index, the odd-row and even-column index, the even-row and odd-column index and the odd-row and odd-column index, respectively.

W_i^j values are interpolated using the Lanczos interpolation (having good approximation capabilities) and combined with the LR input image. Since C_i contains low-pass-filtered image of the LR input image, therefore, high-frequency information is lost. To cater for it, the LR input image is used instead of C_i .Although DT-CWT is shift invariant it may introduce artifacts after the interpolation of W_i^j .Therefore NLM filtering is used to compensate for these artifacts,.

All interpolated W_i^j values are passed through the NLM filter. Then the inverse DT-CWT is applied to these filtered subbands along with the interpolated LR input image to reconstruct the High resolution(HR) image. The results reveal that the proposed algorithm performs better than the existing wavelet-domain RE algorithms in terms of the peak-signal-to-noise ratio (PSNR).The output image will have sharper edges than the interpolated image obtained by interpolation of the input image directly.

The PSNR calculates the peak signal-to-noise ratio, in decibels, between two images. This ratio is used as a quality measurement between the original and a reconstructed image. The higher the PSNR, the better the quality of the reconstructed image.

The MSE(Mean Squared Error) represents the cumulative squared error between the reconstructed and the original image, whereas PSNR represents a measure of the peak error. The lower the value of MSE, the lower the error. To compute PSNR the mean-squared error 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 M and N are the number of rows and columns in the input image.

PSNR can be calculated as follows

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

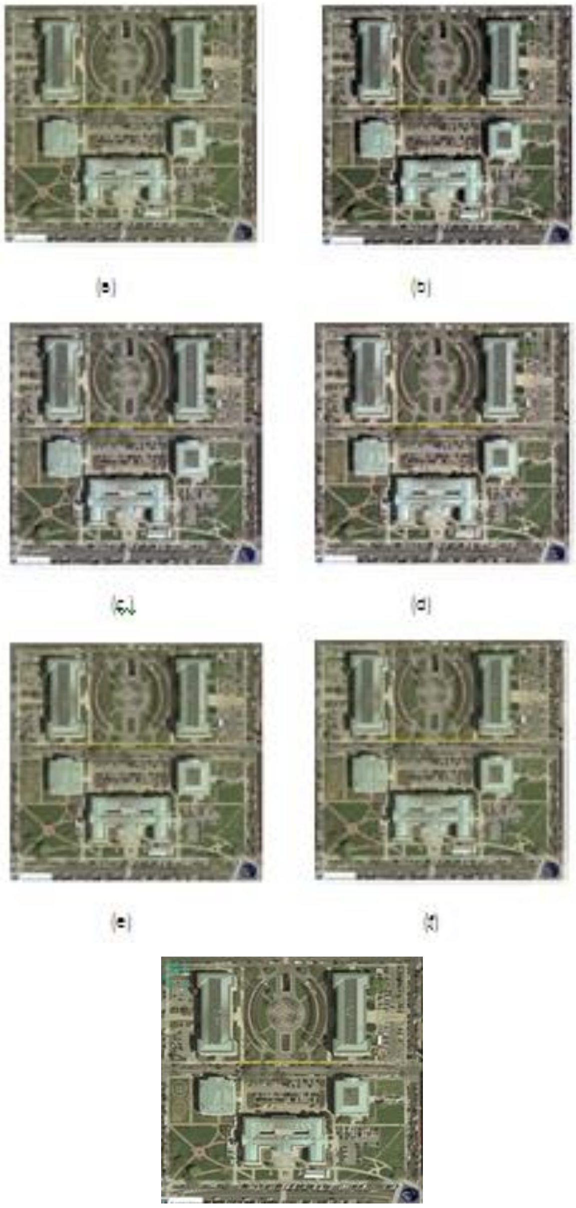
where R is the maximum fluctuation in input image. For a 8-bit image value of R is 255.The Mean Square Error (MSE) and the Peak Signal to Noise Ratio (PSNR) are the two error metrics used to compare image reconstruction quality.

IV. RESULTS AND DISCUSSION

This section presents the results obtained for the proposed 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 SWT,DWT,DT-CWT and DT-CWT_NLM schemes .Figure 3 shows the original “Washington DC” image, the down sampled input image, and the images obtained using SWT-RE , DWT-RE , DT-CWT-RE,DWT-CWT-NLM-RE and the proposed RE schemes.

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 Figure 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 Figure 3(d).

The HR image reconstructed using DT-CWT is shown in Figure 3(e). is shown in Figure 3(f) .The HR image reconstructed using DT-CWT contains few artifacts and hence high frequency subbands are passed through NLM filter to cater for these artifacts. The HR image obtained from this DT-CWT-NLM RE Scheme is shown in Figure 3(f).



(g)

Figure 3 (a) Original "Washington DC" image (b) Input image (c) SWT- RE(d)DWT-RE (e) DT-CWT-RE (f)DT-CWT-NLM-RE (g) Proposed RE scheme

The HR image obtained by the proposed RE scheme has higher resolution compared to the other RE schemes and is shown in Figure 3(g).

Table 1 shows the PSNR comparisons of the proposed technique over the other resolution enhancement schemes like DT-CWT-NLM,DT-CWT, DWT and SWT.

Table1 Comparison of PSNR of various RE schemes

Technique Used	PSNR
SWT-RE	12.42
DWT-RE	12..84
DT-CWT-RE	26.72
DT-CWT-NLM-RE	34.90
Proposed Scheme	52.32

Table1 shows that the Proposed DT-CWT-NLM-RE has higher PSNR compared to the other schemes like SWT-RE and DWT-RE,DT-CWT-RE and DT-CWT-NLM-RE.

V. CONCLUSION

A scheme for image resolution enhancement from a single low-resolution image using the dual-tree complex wavelet transform(DT-CWT) with NLM and curvelet transform has been proposed. This technique does curvelet denoising. The technique decomposes the resultant image using DT-CWT. Wavelet coefficients and the LR input image were interpolated using the Lanczos interpolator. DT-CWT is used as it is nearly shift invariant and generates less artifacts, as compared with DWT. NLM filtering is used to eliminate the artifacts generated by DT-CWT.The proposed technique is compared with the conventional RE schemes. The PSNR and visual results shows the superior performance of proposed technique.

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