A Novel Resolution Enhancement Scheme Based on Edge Directed Interpolation using DT-CWT for Satellite Imaging Applications

Pilla Jagadeesh and Jayanthi Pragatheeswaran

Abstract—Image resolution enhancement is a usable process for many image processing applications such as geoscience studies, astronomy and geographical information systems. Image interpolation is popularly used to increase the image resolution, but the potential problem associated with it is to magnify the image many times without loss in image clarity. Most of the classical linear interpolation techniques like bilinear & bi-cubic interpolation methods generate blurred images. By employing dual-tree complex wavelet transform (DT-CWT) on an edge directional interpolation, it is possible to recover the high frequency components which provides an image with good visual clarity and thus super resolved high resolution images are obtained. The obtained simulation results comply with the above stated claim.

Index Terms— Dual-tree complex wavelet transform (DT-CWT), resolution enhancement, Edge directed interpolation, Super resolved images.

1 INTRODUCTION

With the recent advances in low-cost imaging solutions and increasing storage capacities, there is an increased demand for better image quality in a wide variety of applications involving both image and video processing. While it is preferable to acquire image data at a higher resolution, practically one can imagine a wide range of scenarios where it is technically not feasible. In some cases, it is the limitation of the sensor due to low-power requirements as in satellite imaging, remote sensing, and surveillance imaging. The low-resolution data can exist in the form of still images. Furthermore, the observations can be corrupted by motion-induced artifacts either in the case of still images or videos. An improvement in the spatial resolution for still images directly improves the ability to discern important features in images with a better precision.

Interpolation is the technique that which estimate the new pixel from the surrounding pixels available in the low resolution image. But the computational problem is increased as the order of interpolation factor increases. This problem can be resolved by interpolating the image in wavelet domain. But, super-resolution image reconstruction is an ill-posed inverse problem, since the observation process of the original high

resolution object consists of a noisy blurred low resolution observation affected by sampling artifacts, blur and noise. This is mathematically modeled as a nonlinear process consisting of a convolution operator acting on the image, followed by a down sampling operation and the mixing of additive noise in the frequency domain approach using (discrete) Fourier transform and wavelet-transform based methods (using real wavelets).

This difficulty can be recovered by using complex wavelets because it has the properties of shift invariant and good directionality and by constructing the filters in the form of dual tree structure which provide complex-valued wavelets. It eliminates the inverse problem by perfectly reconstructing the both forward and reverse filter banks and such a transform is referred to as called DT-CWT (dual-tree complex wavelet transform) [5-7].

In earlier works [9, 10], the linear interpolations such as nearest neighbor, bilinear and bi-cubic interpolations are used to enhance the resolution of the image. However these techniques produce many artifacts like blurring, blocking etc., To avoid these problems to a greater extent, a good old non-linear interpolation like edge directional interpolation [3] can be applied to images. This is the prime motivation of using edge directed interpolation technique. However, the major drawback of applying interpolation to achieve super resolved image is the smoothed edges leading to blurring effect. In one of the recent work [7], the authors have proposed a technique which is aimed at generating sharper edges and detailed super resolved satellite images than the dual tree complex wavelet transform (DT-CWT) with bi-cubic interpolation.

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To the best of our knowledge, the features of edge directed interpolation is very less exploited and hence it is used in combination with DT-CWT in this paper and appreciable enhancement has been observed in terms of PSNR. This is the major highlight of this paper. The obtained simulation results are compared with the results shown in the very recent work [7].

This paper is organized as follows: section 2 gives a brief review of the technique edge directional interpolation. Section 3 describes the proposed technique DT-CWT based satellite image resolution enhancement algorithm. Section 4 provides some simulation results of the proposed approach and comparisons with the approach [7],[3], and [2]. Section 5 concludes this paper.

2 PRINCIPLE OF EDI TECHNIQUE

The researchers have so far employed linear interpolation techniques such as nearest neighbour, bilinear and bi-cubic interpolations to improve image resolution. But other techniques suffer from blurring edges or from introducing artifacts around edge area. In [7], the authors have applied bi-cubic interpolation, which again, suffers from blocking and blurring. This paper aims and attempts to rectify all the limitations of the work suggested in [7], [2] and [9] by employing a novel edge directional interpolation technique [EDI], to obtain a high resolution image. EDI estimates the pixel along the edges by estimating the covariance of surrounding neighbours while it uses the image data themselves to direct the interpolation. The edge directional interpolation works as follows:

From the flow chart, the sliding windowing technique like kernel function is applied and sobel is applied for the edge detection. If a pixel is related to edge, bilinear interpolation is applied otherwise it will perform geometric transformations based on the estimated elevation angle to find the edges. After that, the interpolation is applied along these edges by estimating the covariance of surrounding neighbours. The logic employed for computing covariance of surrounding neighbours is described under four steps.

Step1-Computing Covariance: Fig.2 illustrates the approach used for computing the covariance in order to estimate the high resolution pixels. By applying eq(1) at pixels locations (1 to 4), denoted in the figure 2, the covariance is estimated.

\[
\hat{y}_{2i+1,2j+1} = \sum_{k=0}^{1} \sum_{l=0}^{1} \alpha_{2k+1,2l+1} y_{2(i+k),2(j+l)}
\]

Where, \( \alpha = R_{xx}^{-1} r_X \), \( R = [R_{kl}] \) \((0 < k,l \leq 3)\)

\[ r = [r_k] \] \((0 < k < 3)\), denotes local covariance characteristics at high resolution.

Step2-Replacing High Resolution \( R_{kl} \), \( r_{kl} \) with Low Resolution: After finding the covariance of the high resolution pixels, \( R_{kl} \), \( r_{kl} \) is replaced by their low resolution pixels \( R_{kl} \), \( r_{kl} \) which couples the pair of pixels along the same direction but at different resolution. As the difference between the covariance of high resolution pixels and the low resolution pixels become negligible the resolution gets higher and higher.

Step3-Interpolate through 45° Rotation: Interpolate the other half by rotating the image by 45° as indicated in Fig. 3 and repeat the steps 1 and 2 until the new interpolated pixels achieves with increased resolution.

Fig. 2. Finding covariance between pixels to estimate the new pixel

Fig. 3. Finding covariance between pixels to estimate the new pixel by rotating 45°
Step 4: Magnified High Resolution Image: Finally, the image is interpolated by the factor of two which results in a high resolution image. The above steps are applied to the pixels related to edge areas and for non-edge pixels, a simple linear interpolation technique such as bilinear interpolation is applied. Finally, by combining both the pixels related to edge areas and non-edge areas, it forms a new high resolution image with good visual clarity and with fewer artifacts such as blurring, smoothing is obtained.

3 DUAL TREE COMPLEX WAVELET TRANSFORM

Kingsbury in his work [6] introduced the dual-tree complex wavelet transform, stating that it is orthogonal and also can be computed faster. The frequency responses of the CWT have 6 orientations at each of the 4 scales (the number of scales is arbitrary, but the number of orientations is fixed) which provide more features in the image. The main advantages of the DT CWT over the real DWT are that the complex wavelets are approximately shift invariant and have separate sub bands for positive and negative orientations. The conventional separable real wavelet suffers from the lack of shift invariance and thus provides just three orientations.

The two sets of filters are jointly designed so that the overall transform is approximately analytic. Let $h_0(n)$, $h_1(n)$ denote the low-pass/high-pass filter pair for the upper FB, and $g_0(n)$, $g_1(n)$ denote the low-pass/high-pass filter pair for the lower FB. Let, the two real wavelets associated with each of the two real wavelet transforms be denoted as $\psi_0(t)$ and $\psi_1(t)$. In addition to satisfying the Perfect Reconstruction conditions, the filters used in DT-CWT are designed such that the complex wavelet $\psi(t) := \psi_0(t) + j\psi_1(t)$ is approximately analytic. Equivalently, they are designed such that $\psi_0(t)$ is approximately the Hilbert transform of $\psi_1(t)$ [denoted $\psi_0(t) \approx H \psi_1(t)$].

Furthermore, the DT CWT also gives much better directional selectivity when filtering multi-dimensional signals. The above mentioned fact has lead to the following properties [6].

- Approximate shift invariance.
- Good directional selectivity in 2-dimensions (2-D) with Gabor-like filters.
- Perfect reconstruction (PR) using short linear-phase Filters.
- Limited redundancy, independent of the number of scales, 2:1 for 1-D.
- Efficient order-N computation—only twice the simple DWT for 1-D (2m times for m-D).

4 PROPOSED EDGE DIRECTION INTERPOLATION USING DT-CWT

The major loss in an image after being super resolved through interpolation technique, is on its high-frequency components (i.e., edges), which is mainly due to the smoothing effects, caused by interpolation. Hence, in order to increase the quality of the super resolved image, preserving the edges is essential. DT-CWT has been employed in order to preserve the high-frequency components of the image. The DT-CWT has good directional selectivity and has the advantage over discrete wavelet transform (DWT). It also has limited redundancy. The DT-CWT is approximately shift invariant, unlike the critically sampled DWT. The redundancy and shift invariance of the DT-CWT implies that DT-CWT coefficients are inherently interpolable.

In the proposed technique, DT-CWT is used to decompose an input image into different sub-band images as shown in Fig. 4. Complex-valued high-frequency sub-band images contain the high-frequency components of the input image. The interpolation is applied only to the high-frequency sub-band images. In the wavelet domain, the low-resolution image is obtained by low-pass filtering of the high-resolution image.
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The two up-scaled images are generated by interpolating the low-resolution original input image and the shifted version of the input image in horizontal and vertical directions. These two real-valued images are used as the real and imaginary components of the interpolated complex low resolution image, respectively, for the IDT-CWT operation.

By interpolating the input image by $\alpha/2$ and the high-frequency sub-band images by $\alpha$ and then by applying IDT-CWT, the obtained output image will contain more sharper edges than the interpolated image obtained without DT-CWT. This is due to the fact that the interpolation of the isolated high-frequency components in the high-frequency sub-band images will preserve more high-frequency components after the interpolation of the respective sub-bands separately than interpolating the input image directly.

In summary, the proposed technique interpolates the input image as well as the high frequency sub-band images obtained through the DT-CWT process. The final high-resolution output image is generated by applying IDT-CWT of the interpolated sub-band images and the input image. In the proposed algorithm, the employed interpolation i.e., edge directional interpolation is the same for all the sub-band and the input images.

The Performance measure like visual clarity and the peak signal to noise ratio (PSNR) are used to evaluate the proposed technique.

5 RESULTS AND DISCUSSIONS
Simulation results presented in this section are obtained using MATLAB 8.0. In this paper, the performance of proposed technique is tested for three different types of satellite images with original size of $128 \times 128$ extracted from the web source [8] is interpolated for a factor of two. In addition to this, to exhibit the superiority of the EDI based on DT-CWT technique, performance analysis of various interpolation techniques like nearest neighbour, bilinear, bi-cubic, edge directed interpolation etc., are also carried out for comparison purpose. The performance comparison is executed in terms of metrics like PSNR & Visual clarity.

All the three low satellite resolution images and their corresponding EDI interpolated versions before and after applying DT-CWT have been visually shown in 6(a),(b) and (c) respectively. It can be observed that an significantly appreciable clarity in all the three images can be vividly seen for super resolved images shown in 6(c).

This amount of clarity in images shown in (c) is because the proposed technique interpolates the high frequency sub-band images with edge directional interpolation to improve the visual clarity at edges than applying the interpolation directly on the image, shown in (b). By comparing the visual qualitative results from the figure, it has been proved that the proposed technique shows more visual clarity than the edge directional interpolation.

Fig. 5. Block diagram of the proposed resolution enhancement algorithm.
Fig. 6. (a) original resolution image of size (128x128), (b) Edge directional interpolated images without DT-CWT. (c) Super resolved image using the proposed technique (256x256)
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Fig. 7. (a) original resolution image (128x128), (b) bi-cubic interpolated images with DT-CWT, (c) Edge directional interpolated images with DT-CWT.

A comparison study among the proposed EDI based DT-CWT and bi-cubic based DT-CWT suggested in [7] has been simulated for a satellite image shown in Fig.7. Fig.7 (c) clearly shows the substantial quality improvement exhibited by the edge directed interpolation technique when combined with DT-CWT. Table I compares the PSNR Performance of the proposed technique with conventional nearest neighbour, bilinear, bi-cubic and edge directional interpolation techniques.

From the tabulated values shown in table 1, it can inferred that appropriate higher PSNR improvement 2 to 4 dB is achieved through the proposed technique when compare with bi-cubic interpolation using DT-CWT suggested by author’s in [7]. Similarly around 12.5dB to 15dBs PSNR enhancement is possible with other techniques listed in table 1.

6 CONCLUSION
This paper proposes a novel super resolution enhancement technique based on edge directional interpolation applying DT-CWT. Its performance has been tested for different kind of satellite images and compared with the traditional interpolation techniques nearest neighbor, bilinear, bi-cubic, edge directional interpolation and bi-cubic with DT-CWT. In all the cases the proposed technique, shows good performance in terms of PSNR and Visual clarity. The main reason of the resolution enhancement with DT-CWT is its ability to preserve more high frequency components than the interpolation without DT-CWT.

<table>
<thead>
<tr>
<th>Techniques/Images</th>
<th>Satellite image(1) PSNR(dB)</th>
<th>Satellite image(2) PSNR(dB)</th>
<th>Satellite image(3) PSNR(dB)</th>
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<tbody>
<tr>
<td>Nearest neighbour</td>
<td>15.3</td>
<td>13.0</td>
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<td>Bi-linear</td>
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<td>13.5</td>
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<td>Bi-cubic</td>
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<td>Bi-cubic with DT-CWT</td>
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<td>EDI with DT-CWT</td>
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<td>30.0</td>
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REFERENCES


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