



# Robust Satellite Image Resolution Enhancement using Double Density Dual Tree Complex Wavelet Transform

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**Abstract** –Image Resolution enhancement (RE) schemes which are based on wavelets have an advantage over conventional methods which suffer from the losing of high frequency contents which causes blurring. The discrete wavelet transform-based (DWT) RE scheme generates artifacts due to a DWT shift-variant property. A wavelet-domain approach based on double density dual-tree complex wavelet transform (DDDT-CWT) is proposed for RE of the satellite images and compared with dual-tree complex wavelet transform(DT-CWT). A satellite image is decomposed by DDDT-CWT to obtain high-frequency subbands. The high frequency subbands and the low-resolution (LR) input image are interpolated and the high frequency subbands are passed through a low pass filter. The filtered high-frequency subbands and the LR input image are combined using inverse DT-CWT to obtain a resolution-enhanced image. Objective and subjective analyses reveal superiority of the proposed technique over the conventional and state-of-the-art RE techniques.

## Introduction

Resolution of satellite images has always been a limiting factor for utilizing remote sensing data such as satellite imaging etc. Spatial and spectral resolutions of satellite unprocessed images are related with each other that is a high spatial resolution is associated with a low spectral resolution and vice versa[1]. So spatial and spectral resolution enhancement(RE) are desirable. Another technique which is widely used for RE is interpolation[2][3]. The interpolation techniques which are commonly used are based on nearest neighbours which include nearest neighbour, bilinear, bi-cubic, and Lanczos. These can also perform reduction of aliasing, sharpness and ringing[4].

Vector-valued image regularization based methods with partial differential equations(VVIR-PDE)[5] and inpainting and zooming which uses sparse representations[6] are now the state of the art in the field. RE schemes which are not based on wavelets suffer from the drawback of losing the high frequency contents which results in blurring effect.

In the research area of RE in the wavelet domain many algorithms such as discrete wavelet transform (DWT)[7], stationary wavelet transform (SWT) [8], and dual-tree complex wavelet transform (DT-CWT) [9] have been proposed[7]–[11]. Using DT-CWT an RE scheme was proposed in[9] and bicubic interpolations, and results were compared with the conventional schemes i.e., nearest neighbour, bilinear, and bicubic interpolations and wavelet zero padding. Based on DWT and bicubic interpolation a scheme was proposed in[7] and results were compared with conventional schemes and the state of art schemes. Dwt is shift variant, which causes artefacts in the RE image, and has a lack of directionality, whereas DT-CWT is almost shift and rotation invariant[13].

In this Paper a Double Density DT-CWT based lowpass filtering based RE technique is proposed using DT-CWT, Lanczos interpolation, and lowpass filtering. Double Density DT-CWT is nearly shift invariant and directional selective, it preserves the usual properties of perfect reconstruction with well-balanced frequency responses [13],

[14].As compared with traditional DWT, DDDT-CWT provides promising results after the modification of the wavelet coefficients and provides less artefacts.For spatial RE of optical images the results are compared with best performing techniques [5],[7]–[9].

## II. WAVELET TRANSFORM DOMAIN

Using Fourier Transform (FT) only the global frequency content of a signal is retrieved, the time information is lost. By using wavelet analysis a multi-resolution analysis is possible. The frequency and time content of a signal is retrieved by Wavelet Transform(WT).The types of wavelet transform are i) Continuous Wavelet Transform (CoWT) ii) Discrete Wavelet Transform (DWT) iii) Complex Wavelet Transform (CWT).By using Fourier transform and Short Time Fourier Transform a multi resolution analysis is not possible so there is a restriction to use these tools in image processing systems ,particularly in image denoising applications. The multi-resolution analysis is possible by using wavelet analysis. A Continuous Wavelet Transform (CoWT) is calculated analogous to the Fourier transform (FT), by performing convolution between the signal and analysis function. The Discrete Wavelet Transform uses filter banks to perform the wavelet analysis.

### A. Complex wavelet transform

A newly introduced technique of DWT, Orthogonal wavelet decompositions, based on separable, multirate filtering systems have been widely used in image and signal processing, largely for data compression. Dual-Tree complex wavelet transform [12] is introduced by Kingsbury which is a very elegant computational structure which displays near shift invariant properties.

In image processing complex wavelets have not been used due to difficulty in

designing complex filters which satisfy perfect reconstruction property.To overcome this Kingsbury proposed Dual-Tree implementation of the CWT (DT CWT) [14], in which two trees of real filters are used to generate the real and imaginary parts of the wavelet coefficients separately.The DWT suffers from following two problems 1] Lack of shift invariance - this results from the down sampling operation at each level. When the input signal is shifted slightly, the amplitude of the wavelet coefficients varies so much. 2] Lack of directional selectivity - as the DWT filters are real and separable the DWT cannot distinguish between the opposing diagonal directions.

First problem of DWT can be avoided if the output of the filter from each level are not down sampled but this may increase the computational cost significantly and resulting undecimated wavelet transform still cannot distinguish between opposing diagonals since the transform is still separable. To distinguish opposing diagonals with separable filters the filter frequency responses are required to be asymmetric for positive and negative frequencies. The way to achieve this is to use complex wavelet filters which can be made to suppress negative frequency components.Compared to separable DWT complex DWT has improved shift-invariance and directional selectivity[13]-[14].

## III. BASIC CONCEPTS OF THE SYSTEM

In wavelet transform applications filter bank plays an important role.It consists of two banks namely, analysis filter bank and synthesis filter bank. The one dimensional filter bank constructed with analysis and synthesis filter bank which is shown in Fig. 1.

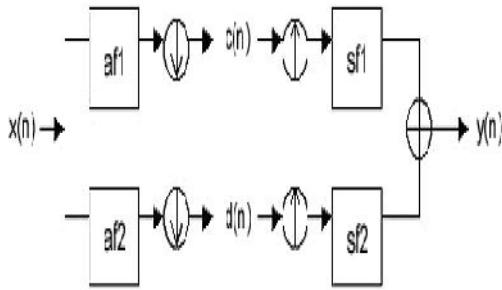


Fig. 1 One dimensional filter bank

The analysis filter bank decomposes the input signal  $x(n)$  into two sub band signals,  $c(n)$  and  $d(n)$ . The signal  $c(n)$  represents the low frequency part of  $x(n)$ , while the signal  $d(n)$  represents the high frequency part of  $x(n)$ . It uses filter banks to perform the wavelet analysis. The DWT decomposes the signal into wavelet coefficients from which the original signal can be reconstructed again. Using wavelet coefficient the signal can be represented in various frequency bands. Using the DWT attractive properties over linear filtering the coefficients can be processed in several ways.

#### A. Basic differences between the two DWT extensions

The main differences between the dual tree Dwt and Double –Density are as follows. 1] The Dual-Tree and Double-Density DWTs are implemented with totally different filter bank structures. 2] The Dual-Tree DWT can be interpreted as a complex-valued wavelet transform which is useful for signal modelling and denoising (the Double-Density DWT cannot be interpreted as such). 3] For the Dual-Tree DWT there are fewer degrees of freedom for design, while for the Double-Density DWT there are more degrees of freedom for design. 4] The Dual-Tree DWT can be used to implement two-dimensional transforms with directional wavelets, which is highly desirable for image processing [15].

## IV. PROPOSED SYSTEMS

Complex wavelet transforms(CWT) concept is introduced so that we can achieve Dual-Tree Complex DWT system. We can achieve Double-Density Dual-Tree Complex DWT system by combining the Double-Density DWT and Dual-Tree Complex DWT. Complex wavelet transforms (CWT) use complex-valued filtering (analytic filter) that decomposes the real/complex signals into real and imaginary parts in transform domain. Amplitude and phase information are calculated by using the real and imaginary coefficients.

#### A. Dual-Tree Complex DWT (DTCWT)

Kingsbury's complex Dual-Tree DWT is based on (approximate) Hilbert pairs of wavelets [15]. Kingsbury found that the Dual-Tree DWT is nearly shift-invariant when the lowpass filters of one DWT interpolate midway between the lowpass filters of the second DWT [16]. Using two critically-sampled DWTs in parallel the Dual-Tree Complex DWT can be implemented as shown in the Fig. 3. For  $N$ -point signal this transform gives  $2N$  DWT coefficients. So this transform is known as 2-times expansive. The design of the filter is done

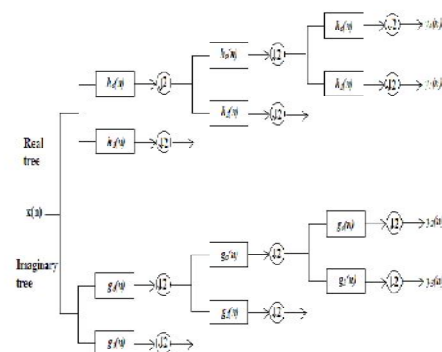


Fig. 2 Design implementation of Dual-Tree Complex DWT

in such a way that the subband signals of the upper DWT can be interpreted as the

real part of a CWT and subbands signals of the lower DWT can be interpreted as the imaginary part. For specially designed sets of filters, the wavelet associated with the upper DWT can be an approximate Hilbert transform of the wavelet associated with the lower DWT. In this manner, the designed DTCWT is nearly shift-invariant than the critically-sampled DWT [10]-[11].

Wavelets are given by DTCWT in six distinct directions. There are two wavelets in each direction. In each direction, one of the two wavelets can be interpreted as the real part and the other wavelet can be interpreted as the imaginary part of a complex-valued two dimensional (2D) wavelet. The DTCWT is implemented as four critically sampled separable 2D DWTs operating in parallel. Different filter sets are used along the rows and columns [10][11]. Fig.4 shows the flowchart of Dual-Tree Complex DWT. This gives the steps of implementation of DTCWT.

#### B. Double-Density Dual-Tree Complex DWT (DDTCWT)

In two dimensions in terms of enhancement Double-Density DWT performs superior than the standard DWT. But here all of the wavelets are not directional. Though more wavelets are utilized by Double-Density DWT, some lack a dominant spatial orientation, which prevents them from being able to isolate those directions [16]. The solution for this problem is provided by the Double-Density Dual-Tree Complex DWT, which combines the characteristics of the Double-Density DWT and the Dual-Tree DWT. The DDTCWT is based on two scaling functions and four distinct wavelets, each of which is specifically designed such that the two wavelets of the first pair are offset from one other by one half, and the other pair of wavelets form an approximate Hilbert transform pair [16]. The DDTCWT is 4-times expansive. In

the same dominating orientations it yields two wavelets [17].

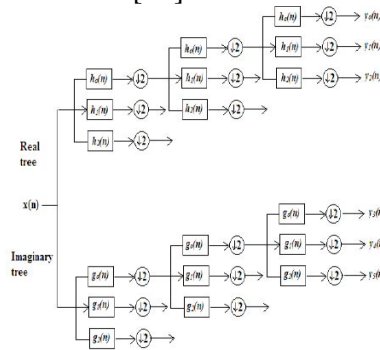


Fig. 3

#### Design implementation of the Double-Density Dual-Tree Complex DWT

One of the wavelets can be interpreted as the real part and the other can be interpreted as the imaginary part for each of the directions. By applying four 2D Double-Density DWTs in parallel with distinct filter sets for the rows and columns this transform can be implemented. Then the sum and difference of the subband images is carried out. This operation gives the 32 oriented wavelets [18]. Fig. 4 shows that design implementation of Double-Density Dual-Tree Complex DWT. The DDTCWT is an over complete discrete wavelet transform (DWT) designed to simultaneously possess the properties of the Double-Density DWT and the Dual-Tree DWT [14].

## RESULTS AND DISCUSSION

The implementation of this work has performed in MATLAB software. The input images are shown in Fig. 4. Fig. 5 shows the results. Fig. 4 shows the input image with different blurring factors. Fig 5 shows the corresponding enhanced images. The performance of both the image resolution enhancement methods can be compared by comparing PSNR (Peak-Signal-to-Noise Ratio) value of each method. Here as Double-Density Complex DWT gives better result than Dual-Tree Complex DWT. Table 1 shows the PSNR values for DT-CWL and DDDT-CWT



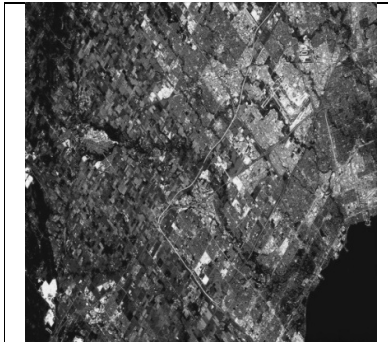


Fig. 5.1 Reconstructed High resolution image 1. PSNR : 42.07



Fig. 5.2 Reconstructed High resolution image 2. PSNR : 40.4958



Fig. 5.3 Reconstructed High resolution image 3. PSNR : 40.5199

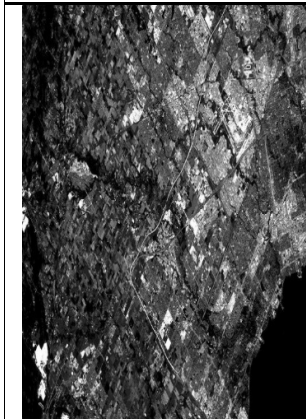


Fig. 4.1 Input test image 1 - high resolution

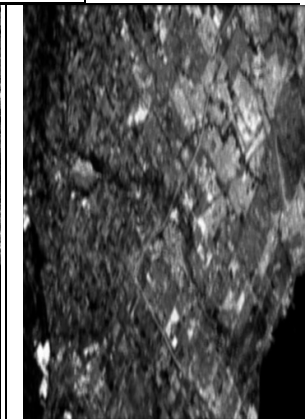


Fig 4.2 - Low resolution Image1

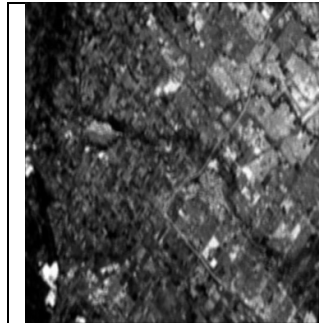


Fig. 4.3-low resolution Image 2

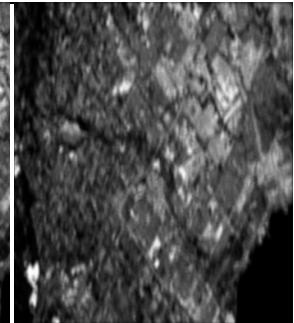


Fig 4.4 - Low resolution Image 3

Fig 4. The various test images used – the high resolutions ones on the left and the corresponding low resolution ones on the right.

Fig 5. Results of the image enhancement based on Double Density Dual Tree Wavelet Transform for different blurring factors

IMAGE NO.	DT CWT	DDDT CWT
Image no. 1 (Fig. 5.1)	38.24	42.07
Image no. 2 (Fig. 5.2)	38.35	40.49
Image no. 3 (Fig. 5.3)	36.39	40.51

TABLE 1. PSNR values of reconstructed images using DT CWT and DDDT CWT.

## CONCLUSION

The newly invented extensions of the DWT perform best in image processing applications. In this paper, the concept focused is wavelet based image resolution enhancement methods of an image which is corrupted by image blurring. The techniques used are Dual-Tree Complex DWT and Double-Density Dual-Tree Complex DWT. These techniques give high performance as compared to the existing basic DWT methods. As blurring increases Double-Density Dual-Tree Complex DWT works superior than Dual-Tree Complex DWT. The DDDT-CWT has the ability to remove the noise in the images as well. The future work will be in the form of application of both the methods to video signals.

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