state of art and conventional techniques for Satellite Image enhancement.

2. Image Resolution Enhancement Techniques

Several research papers and reports were addressed the subject of resolution enhancement and PSNR improvement of an image by using several image resolution enhancement techniques and algorithms. Wavelets play a significant role in multi resolution analysis. In this section we review past work relevant to the image resolution enhancement. A literature survey in this area finds a significant amount of work in knowing about different techniques employed in enhancing the resolution of the images.

2.1 Discrete Wavelet Transform

DWT decompose the image into different subband images namely LL, LH, HL and HH. The frequency components of the subbands cover the full frequency spectrum of original image. Interpolation can be applied to these four subband images. In wavelet domain the low resolution image is obtained by low pass filtering of the high resolution image. The low resolution image (LL-subband) is used as input in this resolution enhancement process. Interpolation carried out using adjacent pixel algorithm. In parallel the low resolution input image is also interpolated separately. Finally Inverse DWT has been applied to combine high frequency subband images and interpolated input image to achieve a high resolution output image.

2.2 Stationary Wavelet Transform

The SWT is wavelet transform algorithm is similar to that of DWT, just the size of subbands produced by SWT is same as that of input image size because it not use down sampling as it is used in DWT, Which is created to remove lack of translation invariance of DWT. Information loss occurs due to down sampling in each of the DWT subbands caused in the respective subbands. SWT also known as undecimated wavelet transform. As like DWT, the SWT also divides the input image into different subbands. The SWT is an inherently redundant scheme as the output of each level of SWT contains the same number of samples as the input. So for a decomposition of N level there is a redundancy of N in the wavelet coefficients.

2.3 Dual Tree-Complex Wavelet Transform

In order to reduce the artifacts, the Dual tree Complex wavelet Transform (DT-CWT) technique is used for satellite images. It is also used in terms of reduction of aliasing that is distortion to the image, ringing that is unwanted oscillation of a signal presented in an image. Moreover, DT-CWT preserved the usual properties of perfect reconstruction with well balanced frequency responses. DT-CWT gives promising results after the modification of the wavelet coefficients as compared with traditional DWT, in which the frequency of an image may not be continuous due to shift variant property. So the DT-CWT is used to overcome it and has significant advantages over real wavelet transform for certain image processing problems.

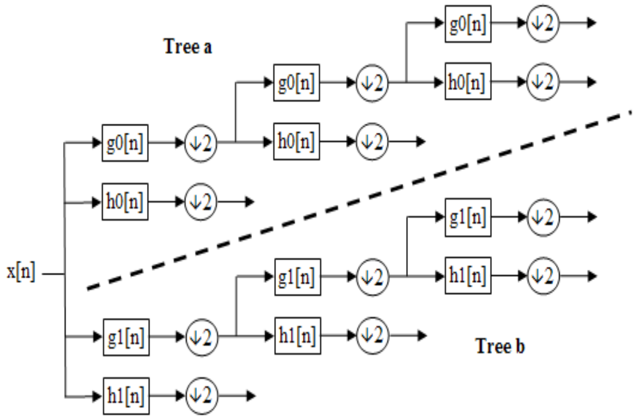

Figure 1: Dual Tree Complex Wavelet Transform (DT-CWT) structure

DT-CWT is a form of DWT, which generates complex coefficients by using a dual tree of wavelet filters to obtain their real and imaginary parts. The output of each tree are down sampled by summing the outputs of the two trees during reconstruction and the aliased components of the image are suppressed and approximate shift invariance is achieved. The shift invariance and directionality of the DT-CWT may be applied in many areas of image processing like denoising, future extraction, object segmentation and image classification.

The DT-CWT of an image produces two complex valued low frequency subband images and six complex valued high frequency subband images. The high frequency subband images are the result of direction selective filters. They show peak magnitude responses in the presence of image features oriented at ±75º, ±15º, and ±45º directions with 4:1 redundancy. After that the interpolation is applied to the high frequency subband images.

In wavelet domain the low resolution image is obtained by low pass filtering of the high resolution image. Therefore, in place of using low frequency subband images which contain less information than the original input image, we are using the input low resolution image for the interpolation. By interpolating the input image by β/2 and the high frequency subband images by β and then applying Inverse DT-CWT operation to get super resolved image. This is due to the fact that the interpolation of the isolated high frequency components will preserve more than the interpolating the input image directly.

3. Interpolation

Interpolation has been used for Resolution Enhancement in image processing widely. The lanczos interpolation, which is a windowed form of Sinc filter, is better than its counterparts (including Nearest Neighbour, Bilinear and Bicubic) because it has the increased ability to detect edges and linear features. It is basically a Fourier kernel. This method uses the same 4x4 input cell neighbourhood as the bicubic methods but a different mathematical combination of the input cell values. Lanczos filter is a mathematical interpretation and it is used to smoothly interpolate the value of a digital signal between its sample signals. It maps each sample of the given signal to a translated and scaled copy of the lanczos kernel. The effect of each input sample on the interpolated values is defined by the filter's reconstruction kernel $L(x)$

$$L(x) = \begin{cases} 1 & if\ x = 0 \\ \dfrac{a \sin(\pi x) \sin(\pi x/a)}{\pi^2 x^2} & if\ 0 < |x| < a \\ 0 & other\ wise \end{cases}$$

The parameter 'α' is a positive integer, typically 2 or 3, which determines the size of the kernel. The Lanczos kernel has 2α -1 lobes, a positive one at the centre and α-1 alternating negative and positive lobes on each side.

4. Edge Preserving Smoothing

The main loss of an image after being resolution enhanced by applying interpolation is on its high frequency components, which is due to smoothing caused by interpolation. The problem of image smoothing is to reduce undesirable distortions, due to the presence of noise or the poor image acquisition process and that negatively affects analysis and interpolation processes, while preserving important features such as homogeneous regions, discontinuities, edges and textures. In order to increase the quality of super resolved image, it is essential to preserve all the edges in an image. Filtering is perhaps the most fundamental operation of image processing and computer vision. Examples of edge preserving smoothing are Bilateral Filter, Guided Filter and Anisotropic Diffusion. Guided filter is an explicit image filter, derived from a local linear model; it generates the filtering output by considering the content of a guidance image, which can be the input image itself or another different image.

Bilateral filtering smoothes images while preserving edges, by means of a nonlinear combination of nearby image values. This method is noniterative, local and simple scheme for edge preserving smoothing. This can be based on a Gaussian distribution. In particular, Gaussian low pass filtering computes a weighted average of pixel values in the neighborhood, in which the weights decrease with distance from the neighborhood center. It combines gray levels or colors based on both their geometric closeness and their photometric similarity and prefers near values to distinct values in both domain and range.

The Bilateral Filter defined as

$$I_{filtered}(x) = \frac{1}{W_p} \sum_{x_i \in \Omega} I(x_i) f_r(\|I(x_i) - I(x)\|) g_s(\|x_i - x\|)$$

Where the normalization term

$$W_p = \sum_{x_i \in \Omega} f_r(\|I(x_i) - I(x)\|) g_s(\|x_i - x\|)$$

Ensures that the filter preserves image energy and I is the original input image to be filtered, x_i are the components of the current pixel, **Ω** is the window centered in x_i, f_r is the range kernel for smoothing differences in intensities and g_s is the spatial kernel for smoothing differences in coordinates.

As mentioned above, the weight W_p is assigned using the spatial closeness and the intensity difference. Consider a pixel located at **(i, j)** which needs to be denoised in image using its neighboring pixels and one of its neighboring pixels is located at **(k, l)**. The weight assigned for pixel **(k, l)** to denoise the pixel **(i, j)** is given by

$$W(i,j,k,l) = e^{\left[-\frac{(i-k)^2+(j-l)^2}{2\sigma_d^2} - \frac{\|I(i,j)-I(k,l)\|^2}{2\sigma_r^2}\right]}$$

Where σ_d and σ_r are smoothing parameters and **I(i, j)** and **I(k, l)** are the intensity of pixels **(i, j)** and **(k, l)** respectively. After calculating the weights normalize them,

$$I_D(i,j) = \frac{\sum_{k,l} I(k,l) * W(i,j,k,l)}{\sum_{k,l} W(i,j,k,l)}$$

Where I_D is the denoised intensity of pixel **(i, j)**. The Bilateral Filter computes the filter output at a pixel as a weighted average of neighboring pixel. Due to this nice property, it has been widely used in noise reduction, HDR compression, multi scale detail decomposition and image abstraction.

5. Proposed Technique

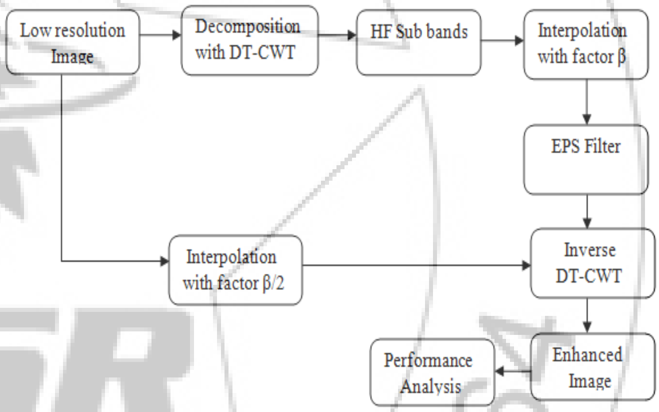

Figure 2: Block diagram of proposed DT-CWT-EPS

5.1 Image Resolution Enhancement Algorithm

In the proposed algorithm (DT-CWT-EPS), we decompose the LR input image (for the multichannel case, each channel is separately treated) in different subbands by using DT-CWT as shown in Fig.1 (i.e. image coefficient subbands and wavelet coefficient subbands). Image coefficient subband contains low pass filtered image of the LR input image, therefore, high frequency information is lost. To cater for it, we have used the LR input image instead of image coefficient subbands. The HF subbands are interpolated by factor β using the Lanczos interpolation (having good approximation capabilities) and combined with the β/2 interpolated LR input image. Although the DT-CWT is almost shift invariant, however, it may produce artifacts after the interpolation of wavelet coefficient subbands. Therefore, to cater for these artifacts Edge Preserving Smoothing (EPS) filter is used. All interpolated wavelet coefficient subbands are passed through the EPS filter. Then we apply the Inverse DT-CWT to these filtered subbands along with the interpolated LR input image to reconstruct the super resolved image. The resolution enhancement is achieved by using directional selectivity provided by DT-CWT, where the high frequency subbands contribute to the sharpness of the high frequency details in six different directions, such as edges.

The Mean square Error (MSE) represents the cumulative squared error between the reconstructed and the original image. The low value of *MSE* leads to low value of error.

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2$$

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

The Peak Signal to Noise Ratio (PSNR) is used as a quality measurement between the original and a reconstructed image. PSNR usually expressed in terms of logarithmic decibel value. PSNR adjusts the quality of the image which the higher the PSNR refers to the better quality is the image.

The PSNR be calculated as

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

Where '*MAX*' is the maximum fluctuation in input image, for an 8-bit image, value of '*MAX*' is 255. Thus the *MSE* and *PSNR* are two error metrics used to compare image reconstruction quality. Objective image quality measures play important roles in various image processing applications. Let $X = \{x_i | i = 1,2,\ldots,N\}$ and $Y = \{y_i | i = 1,2,\ldots,N\}$ be the original and the test image signals, respectively. The proposed quality index is defined as

$$Q = \frac{4\sigma_{xy}\bar{x}\bar{y}}{(\sigma_x^2+\sigma_y^2)[\bar{x}^2+\bar{y}^2]}$$

Where#

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i,\ \bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$$

$$\sigma_x^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2,\ \sigma_y^2 = \frac{1}{N-1}\sum_{i=1}^{N}(y_i - \bar{y})^2$$

$$\sigma_{xy} = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})$$

The dynamic range of Q is [-1, 1]. The best value 1 is achieved if and only if $y_i = x_i$ for all $i = 1,2,\ldots,N$.

6. Results and Discussion

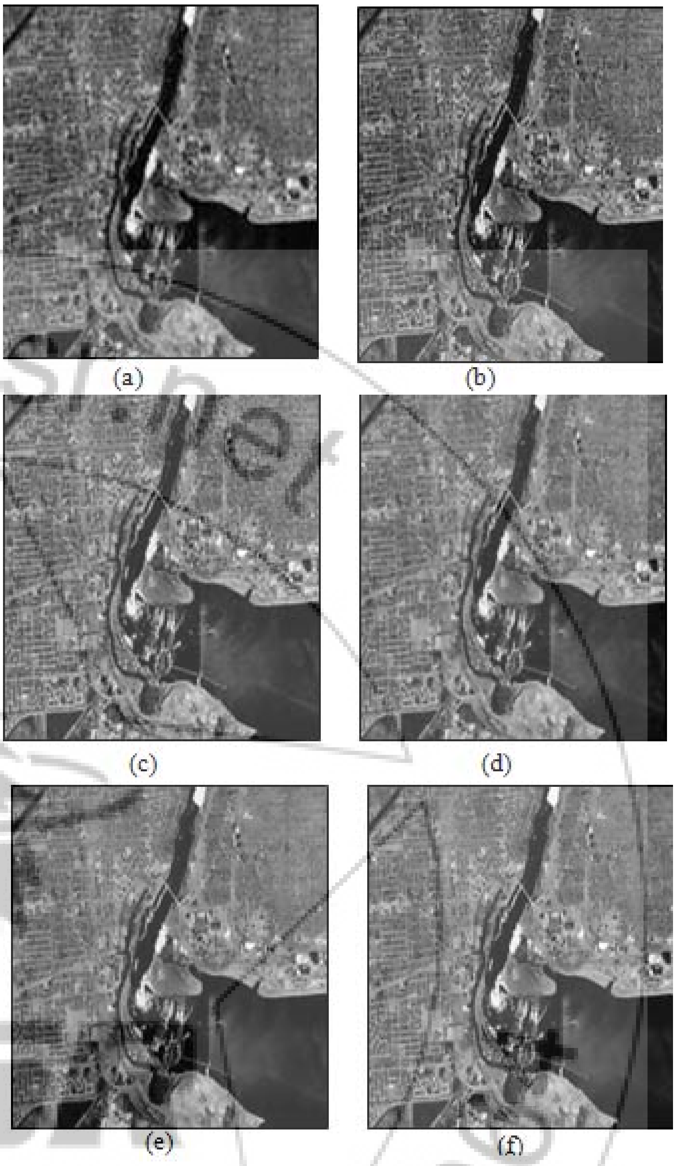

Figure 3: (a) Input image. (b) DWT-RE. (c) DWT-SWT-RE. (d) DT-CWT-NLM-RE. (e) DT-CWT-EPS (Guided) (f) DT-CWT-EPS (Bilateral).

To evaluate the performance of the proposed image enhancement method, we use different test images. The test is conducted on images of different noise levels. The proposed algorithm is compared with the other methods such as DWT, DWT-SWT, DT-CWT-NLM. The performance is evaluated using the quality measures such as MSE, PSNR and IQI. The Image Quality Index (IQI) of the denoised image is defined as product of three factors, Loss of correlation, Luminance distortion and Contrast distortion. Fig.3 shows the RE images of input image. To ascertain the effectiveness of the proposed DT-CWT-EPS algorithm over other wavelet domain RE techniques, different LR optical images obtained from the Satellite Imaging corporation web page were tested. Note that the LR image has been obtained by down sampling the original HR image by a factor 4.

Table 1: Comparisons of the Existing and Proposed Techniques for the Input image shown in Fig. 3(a).

Algorithm	*MSE*	*PSNR(dB)*	*IQI*
DWT- RE	0.0052	70.9802	0.7693
DWT-SWT-RE	0.0029	73.4708	0.8189
DT-CWT-NLM-RE	0.0026	73.9517	0.8385
Proposed DT-CWT– EPS (Guided)	0.0025	74.2391	0.8560
Proposed DT-CWT- EPS (Bilateral)	0.0019	85.3109	0.9922

Table-1 shows the proposed techniques provide improved results interns of MSE, PSNR and Q- Index as compared with other techniques. It can be clearly shows that the results of the proposed algorithm DT-CWT-EPS are much better than the RE images obtained using other techniques. Not only visual comparison but also quantitative comparisons are confirming the superiority of the proposed method.

7. Conclusion

This paper proposes a novel image resolution enhancement technique based on DT-CWT and EPS filter. The technique decomposes the LR input image using DT-CWT. Wavelet coefficients and Input image were interpolated using the Lanczos interpolator. DT-CWT is used since it is shift invariant as well as directional selective and generates fewer artifacts; as compared with DWT. EPS (Bilateral) filtering is used to preserve the edges and denoising the image and to further enhance the performance of the proposed technique interms of MSE, PSNR and Q-Index. Simulation results highlight the superior performance of proposed technique.

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