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Satellite Image Resolution Enhancement Using Multi Scale Decomposition and Anisotropic Diffusion

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Abstract— **Nowadays satellite images are used in many applications such as astronomy, geographical information systems and geosciences studies. Due to low frequency nature of satellite images it may appear as blurred images. To increase the frequency of these images, image resolution enhancement techniques are used. In this paper we propose a new satellite image resolution enhancement technique based on Multi Scale Decomposition and Anisotropic Diffusion. In the proposed resolution enhancement technique uses Dual Tree Discrete Wavelet Transform (DT-DWT) to decompose an input low resolution satellite image into different sub bands. Combine the filtered high frequency sub bands and the low resolution input image using Inverse DT-DWT to reconstruct a resolution enhanced image. Then, apply the Anisotropic Diffusion (an Edge preserving smoothing filter) to this image for denoising the image and to cater for the artifacts generated by DT-DWT. The quantitative (Peak signal to noise Ratio and Mean square Error) visual results show the superiority of the proposed technique over the conventional resolution enhancement techniques.**
Keywords – Resolution Enhancement (RE), Interpolation, Dual Tree Discrete Wavelet Transform (DT-DWT), Edge Preserving Smoothing (EPS).

I. INTRODUCTION

Image enhancement is the procedure of manipulating an image so that the resultant image is more suitable than the original image for a specific application. Satellite images are used in many fields of research. The quality and quantity of satellite imagery is largely determined by their resolution. There are four types of resolution when discussing the satellite imagery in remote sensing: spatial, spectral, temporal and radiometric. *Spatial Resolution* is the measure of how lines are closely resolved in an image. In remote sensing, it is typically limited by diffraction, as well as imperfect focus and atmospheric distortion, etc. *Spectral Resolution* is defined by the discrete segment of the Electromagnetic spectrum (wavelength interval size) and number of intervals that the sensor is measuring. *Temporal Resolution* is defined by the amount of time that passes between imagery collection periods for a given surface location. *Radiometric Resolution* determines how finely a system can represent or distinguish differences of intensity and usually expressed as number of levels or number of bits. A common RE technique is to improve number of pixels to represent the details of an image. Interpolation in image processing is a prominent method to increase the resolution of a digital image.Interpolation has been used over a broad range in many image processing applications such as facial reconstruction, multiple description coding and resolution enhancement. Based on nearest neighbor pixel insertion commonly used interpolation techniques include Nearest neighbor interpolation, Bilinear interpolation, Bicubic interpolation. The Bicubic interpolation is superior to its counterparts due to increased ability to detect edges and linear features. It also offers the best compromise interns of reduction of aliasing, sharpness and ringing.RE schemes that are independent of wavelets (interpolation methods) suffer from the drawback of losing high frequency components leads to blurring. In RE by using interpolation the main loss is on its high frequency components (i.e. edges) because of smoothing caused by interpolation. Image RE in wavelet domain is a new research area, in order to preserve the high frequency components of the image. Recently many RE algorithms have been proposed (DWT, SWT, DT-DWT). Dual Tree- Discrete Wavelet Transform is the most recent wavelets transform used in RE. Discrete wavelet Transform (DWT) decomposes an image into different subband images, namely LL, LH, HL and HH. DWT is shift variant, which causes artifacts in the RE image and has a lack of directionality. Another wavelet transform which has been used in several image processing applications is Stationary Wavelet Transform (SWT). Down sampling in each of the DWT sub bands causes information loss in the respective sub bands. That's why SWT is employed to minimize this loss. In short, SWT is similar to DWT but it does not used down sampling, therefore the sub bands will have the same size as the input image. Note that Dual Tree-

Discrete Wavelet Transform (DT-DWT) is shift (or rotation) invariant and directional selective. In this letter, a Multi scale Decomposition and Edge preserving Smoothing based image resolution enhancement (DTDWT-EPS) technique is proposed which generates sharper high resolution image. According to the quantitative and visual results, the proposed technique outperforms the aforesaid state of art and conventional techniques for Satellite Image enhancement.

II. 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.

A. DISCRETE WAVELET TRANSFORM

DWT decompose the image into different subband images namely LL, LH, HL and HH. The frequency components of the sub bands 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.

B. STATIONARY WAVELET TRANSFORM

The SWT is wavelet transform algorithm is similar to that of DWT, just the size of sub bands 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 sub bands caused in the respective sub bands. SWT also known as undecimated wavelet transform. As like DWT, the SWT also divides the input image into different sub bands. 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.

C. DUAL TREE –DISCRETE WAVELET TRANSFORM

In order to reduce the artifacts, the Dual Tree Discrete Wavelet Transform (DT-DWT) 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-DWT preserved the usual properties of perfect reconstruction with well balanced frequency responses. DT-DWT gives promising results after the modification of the wavelet coefficients and provides less artifacts, as compared with traditional DWT, in which the frequency of an image may not be continuous due to shift variant property. So the DT-DWT is used to overcome it and has significant advantages over real wavelet transform for certain image processing problems.

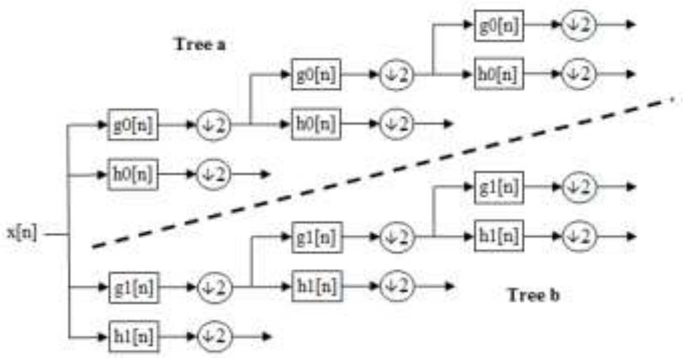

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Figure-1: Dual Tree Discrete Wavelet Transform (DT-DWT) structure

The DT-DWT 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-DWT 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.

III. INTERPOLATION

Interpolation has been widely used in image processing widely. In mathematics, Bicubic interpolation is an extension of cubic interpolation for interpolating data points on a two dimensional regular grid. The interpolated surface is smoother than corresponding surfaces obtained by bilinear interpolation or nearest-neighbor interpolation. Bicubic interpolation can be accomplished using either Lagrange polynomials, cubic splines, or cubic convolution algorithm. In image processing, bicubic interpolation is often chosen over bilinear interpolation or nearest neighbor in image resampling, when speed is not an issue. In contrast to bilinear interpolation, which only takes 4 pixels (2×2) into account, bicubic interpolation considers 16 pixels (4×4). Images resampled with bicubic interpolation are smoother and have fewer interpolation artifacts.

Suppose the function values f and the derivatives f_x, f_y and f_{xy} are known at the four corners $(0,0)$, $(1,0)$, $(0,1)$, and $(1,1)$ of the unit square. The interpolated surface can then be written

$$p(x,y) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij} x^i y^j.$$

IV. 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.

Anisotropic diffusion: Nonlinear anisotropic diffusion filtering is a procedure based on nonlinear evolution partial differential equations which seeks to improve images qualitatively by removing noise while preserving details and even enhancing edges. In particular, Perona and Malik proposed the following nonlinear diffusion approach to image filtering. It produces a family of parameterized images, but each resulting image is a combination between the original image and a filter that depends on the local content of the original image.

Formally, let $\Omega \subset \mathbb{R}^2$ denote a subset of the plane and $I(\cdot,t) : \Omega \rightarrow \mathbb{R}$ be a family of gray scale images, then anisotropic diffusion is defined as

$$\frac{\partial I}{\partial t} = \operatorname{div}\left(c(x,y,t)\nabla I\right) = \nabla c \cdot \nabla I + c(x,y,t)\Delta I$$

where Δ denotes the Laplacian, ∇ denotes the gradient, $\operatorname{div}(\dots)$ is the divergence operator and $c(x, y, t)$ is the diffusion coefficient. $c(x, y, t)$ controls the rate of diffusion and is usually chosen as a function of the image gradient so as to preserve edges in the image. Pietro Perona and Jitendra Malik pioneered the idea of anisotropic diffusion in 1990 and proposed two functions for the diffusion coefficient:

$$c\left(\|\nabla I\|\right) = e^{-\left(\|\nabla I\|/K\right)^2}$$

$$c\left(\|\nabla I\|\right) = \frac{1}{1 + \left(\frac{\|\nabla I\|}{K}\right)^2}$$

the constant K controls the sensitivity to edges and is usually chosen experimentally or as a function of the noise in the image.

V. PROPOSED TECHNIQUE

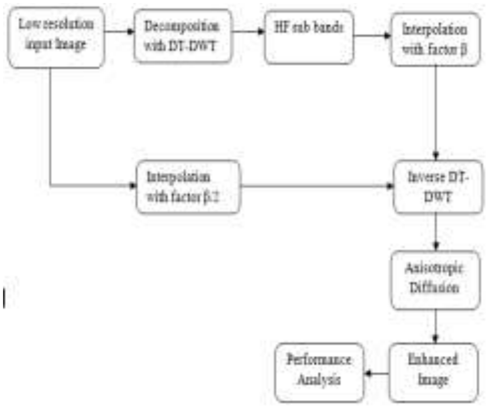

Figure-2: Block diagram of proposed DT-DWT-EPS Image Resolution Enhancement Algorithm

In the proposed algorithm (DT-DWT-EPS), we decompose the LR input image (for the multichannel case, each channel is separately treated) in different sub bands by using DT-DWT as shown in Fig.1 (i.e. image coefficient sub bands and wavelet coefficient sub bands). 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 sub bands. The HF sub bands are interpolated by factor β using the bicubic interpolation (having good approximation capabilities) and combined with the β/2 interpolated LR input image. Then we apply the Inverse DT-DWT to these filtered sub bands along with the interpolated LR input image to reconstruct the super resolved image Although the DT-DWT is almost shift invariant, however, it may produce artifacts after the interpolation of wavelet coefficient sub bands. Therefore, to cater for these artifacts Edge Preserving Smoothing (EPS) filter is used. All interpolated wavelet coefficient sub bands are passed through the EPS filter. The resolution enhancement is achieved by using directional selectivity provided by DT-DWT, where the high frequency sub bands 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.

VI. RESULTS AND DISCUSSION

(a)

(b)

(c)

(d)

(e)

Fig. 3. (a) Original LR image (b) DT-DWT-RE (c)DT-DWT-EPS(Bilateral). (d)DT-DWT-EPS(Guided). (e)DT-DWT-EPS (Anisotropic Diffusion).

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 performance is evaluated using the quality measures such as MSE and PSNR. Fig.3 shows the RE images of input image. To ascertain the effectiveness of the proposed DT-DWT-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)**
DT-DWT-EPS(Bilateral)	$8.87\text{x}10^{-8}$	118.64
DT-DWT-EPS(Guided)	$8.83\text{x}10^{-8}$	118.66
DT-DWT-EPS(Anisotropic Diffusion)	$8.81\text{x}10^{-8}$	118.68

Table-1 shows the proposed techniques provide improved results interns of MSE and PSNR as compared with other techniques. It can be clearly shows that the results of the proposed algorithm DT-DWT-EPS(Anisotropic Diffusion) 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.

CONCLUSION

This paper proposes a novel image resolution enhancement technique based on DT-DWT and EPS filter. The technique decomposes the LR input image using DT-DWT. Wavelet coefficients and Input image were interpolated using the Bi-cubic interpolator. DT-DWT is used since it is shift invariant as well as directional selective and generates fewer arty facts; as compared with DWT. EPS (Anisotropic) filtering is used to preserve the edges and de-noising the image and to further enhance the performance of the proposed technique in terms of MSE and PSNR. Simulation results highlight the superior performance of proposed technique. In future we work to extend this project to get the good efficiency and accurate results.

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