Satellite Image Resolution Enhancement Using Discrete Wavelet Transform and Gaussian Mixture Model

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Abstract - *High Resolution Satellite Images are of a significant importance in many fields of research. For the last few decades Wavelets are playing a key role in image resolution enhancement techniques. In those algorithms, Discrete Wavelet Transform (DWT) is mostly used in image decomposition stage and bicubic interpolation is used in interpolation stage. In this paper, we proposed a new technique based on the image decomposition using DWT and the interpolation using Gaussian Mixture Model (GMM) which is a parametric probability density function represented as a weighted sum of Gaussian component densities instead of weighted sum of neighborhood pixels such as bicubic or bilinear interpolations. This DWT image decomposition and GMM interpolation gives better results than existing techniques and it is proved with the quantitative (peak signal-to-noise ratio and quality index) and visual results over the conventional and state-of-art image resolution enhancement techniques.*

Key Words: Bicubic Interpolation; Discrete Wavelet Transform (DWT); Gaussian Mixture Model (GMM); Peak Signal-to-Noise Ratio (PSNR); Quality Index (QI);

1. INTRODUCTION

Satellite images are being used in many image processing applications such as geoscience studies, weather forecasting, astronomy and geographical information systems [1]. However, high resolution satellite images are essential for better results. The most commonly used image resolution enhancement techniques are: nearest neighbor interpolation, bilinear interpolation and bicubic interpolation [2]. Bicubic interpolation is widely used than the other two techniques and it produces noticeably sharper images [3]. When applying interpolation methods, the high frequency components may be misplaced because of the smoothing effects created during interpolation. It is imperative that pixel values around the edges be preserved to improve the resolution of the image. Wavelets play a vital role in image resolution enhancement techniques to preserve the edges. Discrete Wavelet Transform (DWT) is used in image decomposition stage and bicubic interpolation is used in interpolation stage in many of the wavelet based image resolution enhancement methods [4]. DWT decomposes the image into four sub band images defined as Low-Low (LL), Low-High (LH), High-Low (HL), and High-High (HH).The frequency components of these sub bands cover the full frequency spectrum of the original image. Theoretically, a filter bank should be operated on the image in order to generate different sub band frequency images. Edges identified in lower frequency sub bands are used to prepare the model for estimating edges in higher frequency sub-bands, and only the coefficients with significant values are estimated as the evolution of the wavelet coefficients. Filter bank of DWT is shown in figure1 [5].

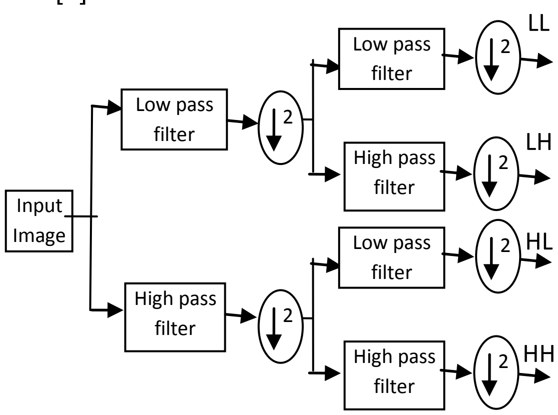

Figure 1. Filter Bank of DWT

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Hasan et al [4] proposed a resolution enhancement technique based on the image decomposition using DWT and coefficients are interpolated using bicubic interpolation. When tested on satellite benchmark images the quantitative and visual results proved that their proposed technique was superior to the conventional image resolution enhancement techniques. Battulla et al., [6], Mohan, et al., [7] and Karunakar et al., [8] also proposed DWT decomposition and interpolation of high frequency components. Salehi and Nasab presented image resolution improvement method based on the complex wavelet transform and feed forward Neural Networks (NN) [9]. The wavelet sub bands of high resolution images are constructed by using the NN using the low resolution sub bands. Dual complex tree properties such as approximate shift variance, directional selectivity and substantial reduced aliasing were used to get detailed representation of the local structures in the interpolated images.

Zhang [10] proposed edge-guided nonlinear interpolation method by using a directional filtering and data fusion. To interpolate a pixel, two observation sets are created in two orthogonal directions, and each set produces an estimate of the pixel value. These estimated sets were modeled as different noisy measurements in missing pixels and fused by the Linear Minimum Mean Square-Error Estimation (LMMSE) technique using the statistics. Experiments proved that the proposed interpolation method preserved the sharpness of edges and reduced the ringing artifacts. Hou et al [11] proposed two synthetic aperture radar complex image compression schemes based on Directional Lifting Wavelet Transform Image Quality (DLWT_IQ) and DLWT_ Fast Fourier Transform (DLWT_FFT). The real parts and imaginary parts of the images are encoded by DLWT_IQ and the real images converted by FFT are encoded by DLWT_FFT.

Bicubic interpolation gives rise to blurred edges. To overcome this, in this paper we proposed a new image resolution enhancement technique using DWT image decomposition and Gaussian Mixture Model (GMM) interpolation. GMM is a flexible, semi-parametric model, yet simple model which makes efficient estimations.

The flow chart for Satellite Image Resolution Enhancement using DWT and bicubic interpolation and image decomposition using DWT and GMM interpolation is shown in figure 2(a) and 2(b) respectively. Figure 2(a), Here DWT is used to decompose an input image into low low (LL), low high (LH), high low (HL) and high high (HH) sub bands. Those sub bands are interpolated using bicubic interpolation technique, followed by combining all these images to generate a new high-resolution image by using inverse DWT and in figure 2(b)DWT is used to decompose an input image into low low (LL), low high (LH), high low (HL) and high high (HH) sub bands. Those sub bands are interpolated using GMM interpolation technique, followed by combining all these images to generate a new high-resolution image by using inverse DWT. Results of these techniques are compared with proposed technique.

This paper is organized as follows: Section2 gives an overview on the bicubic interpolation, Section 3 introduces the proposed DWT and GMM interpolation technique and Section 4 discusses the visual and quantitative results of the proposed techniques. The results of the proposed method are compared with other conventional techniques (bilinear interpolation, bicubic interpolation, wavelet zero padding, DWT image decomposition and bicubic interpolation, DWT image decomposition and GMM interpolation, Both quantitative and visual results show the superiority of the proposed technique. Conclusions are given in the final section.

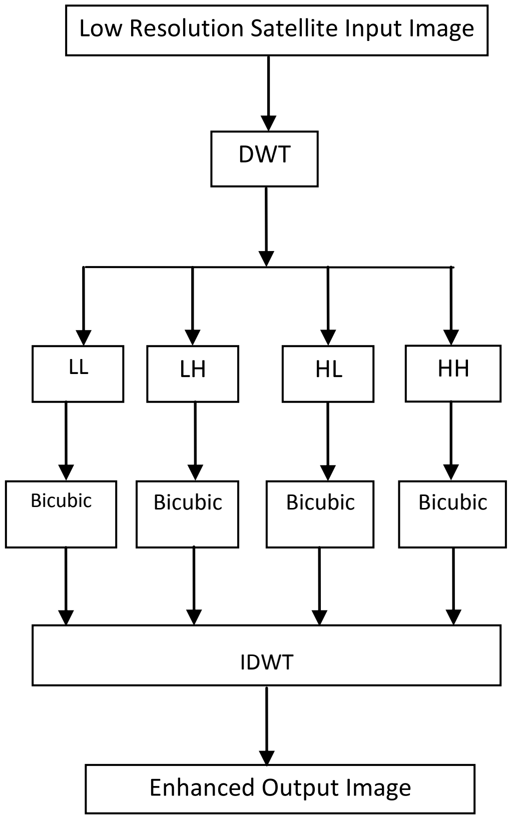


Figure 2(a) Block diagram of Image decomposition using DWT and Bi-cubic interpolation of Satellite Image Resolution Enhancement Technique.

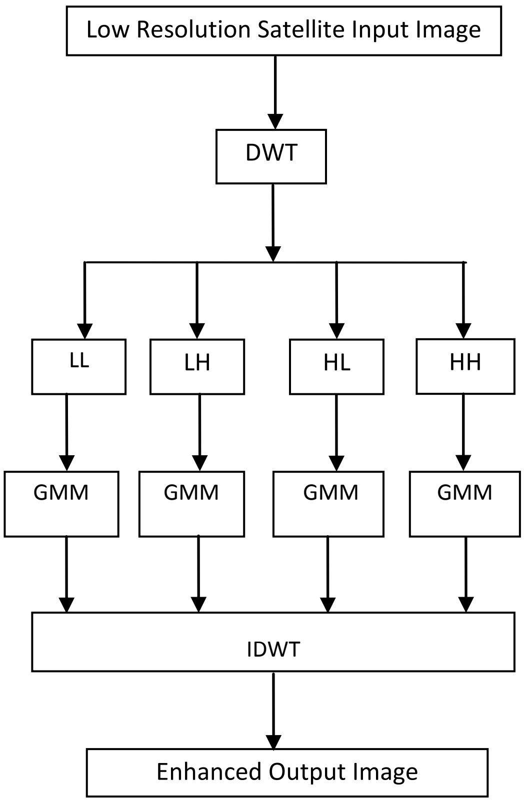


Figure 2(b) Block diagram of Image decomposition using DWT and GMM interpolation of Satellite Image Resolution Enhancement Technique.

2 BICUBIC INTERPOLATION

Interpolation (either linear or non-linear) is one of the commonly used methods for resolution enhancement. In linear interpolation method, mean value of neighboring pixels is used to interpolate at each pixel, but it may create blurred edges and smoothed details. In bilinear interpolation, new pixel value is computed by weighted average of four surrounding pixels. This will be useful for image compression instead of image resolution enhancement to reduce the redundancy. Many non-linear interpolation (bicubic) methods are more powerful than linear methods (bilinear) [6]. However, if the raw image has more lower-frequency information, it is better to use the bilinear interpolation rather than bicubic interpolation. In bicubic interpolation, interpolated point is filled with sixteen closest pixel's weighted average. Sharper images are obtained by using bicubic interpolation method than bilinear interpolation [6].The bicubic convolution interpolation kernel is:

$$w(x)=\begin{cases}(a+2)|x|^3-(a+3)|x|^2+1 & for\ |x|\le 1\\ a|x|^3-5a|x|^2+8a|x|-4a & for\ 1<|x|<2\\ 0 & otherwise\end{cases} \qquad (1)$$

Where a is generally taken as -0.5 to -0.75

3 PROPOSED TECHNIQUE

3.1 Gaussian Mixture Model

Edge structures preservation is a challenging task during the interpolation of images while reconstructing a high-resolution image using low-resolution counterpart. In this proposed technique, input image is decomposed with DWT and coefficients are interpolated with the highest probability of covariance matrix Σi and mean μi rather than weighted average of sixteen neighbour pixels in bicubic interpolation. So it gives sharper edges and better PSNR and QI than bicubic interpolation.

A GMM is a parametric probability density function represented as a weighted sum of Gaussian component densities. GMMs are commonly used as a parametric model of the probability distribution of continuous measurements. The complete Gaussian mixture model is parameterized by the mean vectors, covariance matrices and mixture weights from all component densities. The covariance matrices can be full rank or constrained to be diagonal. Additionally, parameters can be shared, or tied, among the Gaussian components, such as having a common covariance matrix for all components. The choice of model configuration (number of components, full or diagonal covariance matrices, and parameter tying) is often determined by the amount of data available for estimating the GMM parameters and how the GMM is used. It is computed as:
A Gaussian mixture model is a weighted sum of M component Gaussian densities [13]. It is computed as:

$$p(x|\lambda)=\sum_{i=1}^{M} w_i g(x|\mu_i,\Sigma_i) \qquad (2)$$

Where **x** is a D-dimensional continuous-valued data vector and depends on the number of dimensions in the data. In the case of gray scale image D=2.wi, i = 1, . . . , M, mixture weights
g (x|μi,_i), i = 1, . . . ,M, Gaussian densities component. Density component is a D-variate Gaussian function consisting of D dimensions given as,

$$g(x|\mu_i,\Sigma_i)=\frac{1}{(2\pi)^{D/2}|\Sigma_i|^{1/2}}\exp\left\{-\frac{1}{2}(x-\mu_i)'\Sigma_i^{-1}(x-\mu_i)\right\}$$

Where μi is a mean vector and it is given as μi = $\frac{\sum_{i=1}^{n} x_i}{n}$ and Σi is a covariance matrix and it is given as $\Sigma_i = \frac{\sum_{i=1}^{n}(x_i-\bar{x})}{n-1}$

In probability theory, covariance is a measure of how much two random variables change together. The mixture weights satisfy the constraint $\sum_{i=1}^{M} w_i = 1$.Thus, the Gaussian mixture model is represented by the mean vectors, covariance matrices and mixture weights of all component densities.
The problem is formulated to the prediction of wavelet coefficients of an image and use the inverse wavelet transform resulting in increased resolution. Training of

the mixture model is achieved using Expectation Maximization (EM) algorithm. For a given wavelet coefficient 'c' that is governed by a group of parameters θ the density function is given by $p(x|\theta)$. Let N be the size of the coefficients and assuming each coefficient is independent and identically distributed with distribution p, the resulting likelihood can be given by

$$p(C|\theta) = \prod_{i=1}^{N} p(c_i|\theta) = \ell(\theta|C)$$

The function $\ell(\theta|C)$ is called the likelihood of the given input wavelet coefficients.

Using EM algorithm it is possible to find additional values. Assuming the coefficients C is generated by some distribution, it can be stated C is the incomplete and assuming a complete data $E=(C,D)$ exists such that the joint density function is given by

$$p(E|\theta) = p(c,d|\theta) = p(d|c,\theta)\, p(c|\theta)$$

The EM algorithm finds the expected value and is given by

$$O(\theta,\theta^{(i-1)c}) = E\left[\log p(C,D|\theta)|C,\theta^{(i-1)}\right]$$

Where $\theta^{(i-1)}$ are the current parameter estimates used to evaluate expectation.

3.2 Proposed DWT AND GMM Method

Input low resolution satellite image is decomposed using DWT into LL, LH, HL, HHsubbands and these are interpolated using bicubic interpolation technique followed by combining all these images to generate a new high-resolution image by using inverse NDWT along with GMM. Proposed GMM interpolation is advisable in remote sensing applications to get a high-resolution image as the recorded satellite images have both low-frequency and high-frequency elements.

4 Experimental Results

In order to show the improvement in the resolution of satellite images of the proposed method over the conventional and state-of-art image resolution enhancement techniques, two satellite images with different features are used for comparison. Figure.4 shows that high resolution images using the proposed techniques in (f) is much sharper than the original low-resolution images in (a), bilinear interpolation in (b), bicubic interpolation in (c) wavelet zero padding in (d), DWT based image decomposition and bicubic interpolated images in (e). The proposed technique is evaluated in terms of Peak Signal to Noise Ratio (PSNR), and Quality Index (QI) and compared with other techniques. It is clear that the proposed DWT-GMM technique is outperform than bilinear interpolation, bicubic interpolation, wavelet zero padding, DWT based image decomposition and bicubic interpolated techniques.

The PSNR is calculated as follows:

PSNR is the ratio of the maximum possible power of a signal and the power of noise and is expressed in logarithmic decibel scale10.

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \quad (3)$$

$$MSE = \frac{\sum_{i=1}^{X}\sum_{j=1}^{Y}(a_{i,j}-b_{i,j})^2}{xy} \quad (4)$$

MSE is a Mean Square Error, where the terms $a_{i,j}$and $b_{i,j}$ represent the pixel values from actual and the interpolated images respectively and the values X and Y define the height and width of an image respectively.

And the Quality Index is calculated as below:

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

$$Q = \frac{4\sigma_{xy}\bar{x}\,\bar{y}}{(\sigma_x^2+\sigma_y^2)\left[(\bar{x})^2+(\bar{y})^2\right]} \quad (5)$$

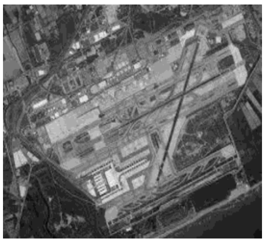
Where $\bar{x} = \frac{1}{N}\sum_{i=1}^{N}x_i$, $\bar{y} = \frac{1}{N}\sum_{i=1}^{N}y_i$

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

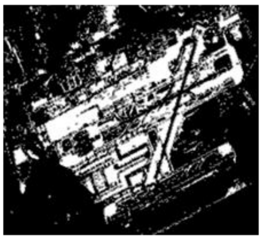
$$\sigma_y^2 = \frac{1}{N-1}\sum_{i=1}^{N}(y_i-\bar{y})^2,$$

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

(a)



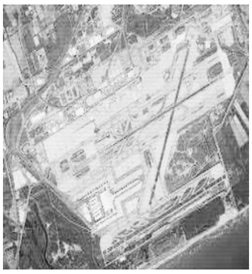
(b)



(c)

(d)

(e)



(f)

Figure 3.Satellite Image of US-Topo (a) Low Resolution Input Image, Resolution Enhanced Images using (b) Bilinear Interpolation, (c) Bicubic Interpolation, (d) Wavelet Zero Padding, (e) DWT based Image decomposition and bicubic interpolated image. (f) DWT based Image decomposition and GMM interpolated image.

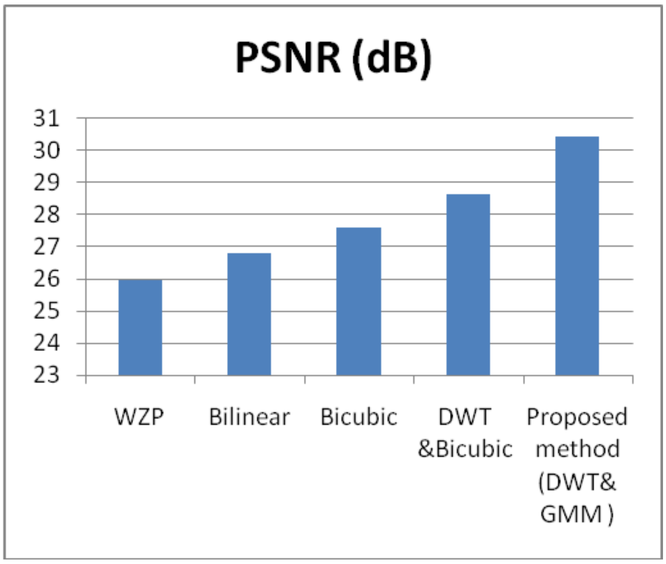


Figure 4 PSNR (Decibels) results for resolution enhancement for the proposed technique compared with conventional and some state-of-art techniques.

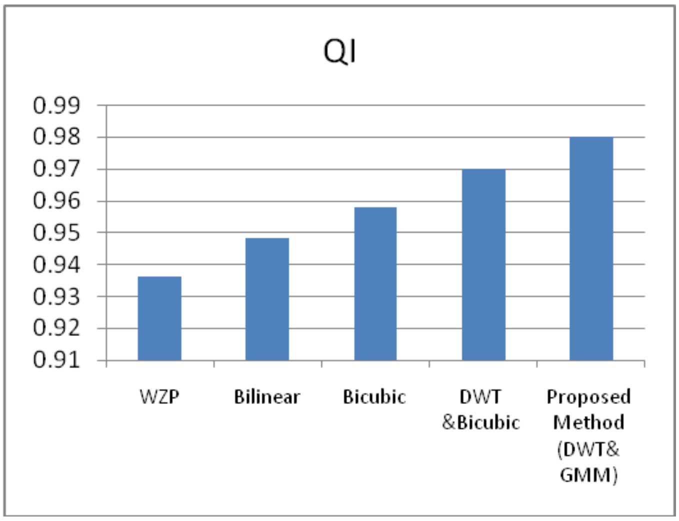


Figure5. Q index for Satellite Image of US-TOPO.

From Figure 4 and 5, it is observed that the PSNR of the proposed approach is 1.80 dB higher than the PSNR of DWT and bicubic interpolation technique.

Results indicate the superiority of the proposed technique over the conventional and image resolution enhancement techniques.

5. CONCLUSION

A new Satellite image resolution improvement technique is achieved by using discrete wavelet transform to decompose the image and Gaussian Mixture Model interpolation to interpolate the coefficients. The results prove that the proposed technique is superior to existing methods. Table 1 lists the PSNR and Q Index achieved for the various techniques.

Table 1: PSNR and QI results for proposed technique compared with conventional image resolution enhancement techniques.

Technique ↓	PSNR (dB)	QI
WZP	25.97	0.9362
Bilinear	28.78	0.9483
Bicubic	27.60	0.9578
DWT &Bicubic	28.64	0.9701
Proposed Method (NDWT &GMM)	30.44	0.9798

It is observed that the proposed DWT and GMM method achieves higher PSNR and Q Index than the existing methods.

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