Gaussian Mixture Model and Lifting Wavelet Transformed Base Satellite Image Enhancement

T. V. Hyma Lakshmi, T. Madhu, K. Ch Sri Kavya

Abstract*: From the last few decades, Satellite images are being used widely in various applications like monitoring of forest areas, weather forecasting, polar bears counting, etc. In those applications to get more details of images efficiently, satellite images should be enhanced up to the required level as the images captured by the satellites are covered very large areas and those are very low-resolution images due to the high altitudes of satellites from the earth. We proposed a method of an image enhancement which includes both resolution enhancement and contrast enhancement. In this method, Stationary Wavelet Transform (SWT) in combination with Lifting Wavelet Transform (LWT) is used for image decomposition into low-frequency sub band images and high-frequency sub band images to separate smooth regions and sharp edges to interpolate regions and edges separately to reduce blurring effect in edges and noise in smooth regions. To get smoother details and sharper edges, Gaussian Mixture Model (GMM) is used for interpolation in resolution enhancement process and SWT with the combination of Contrasts Limited Adaptive Histogram Equalization (CLAHE) for contrast enhancement process. SWT in combination with LWT improves the resolution effectively and also minimizes the execution time drastically than existing methods due to the shift invariance of SWT and reduced computations in LWT and GMM interpolation results from sharper edges and smoother details. SWT is used in combination with CLAHE to enhance the contrast and mitigate the noise effects than existing methods. The proposed method gives superior results and compared with existing techniques with PSNR, Noise Estimation, and visual results.

Index Terms*: Contrasts Limited Adaptive Histogram Equalization (CLAHE), Gaussian Mixture Model (GMM), Lifting Wavelet Transform (LWT), Peak signal to noise ratio (PSNR), Stationary Wavelet Transform (SWT), Weighted Average.

I. INTRODUCTION

Recently Satellite images are using various remote sensing applications [1] like the observation of live volcanoes, assessment of the condition of rural roads and many more. In almost all, those applications, Resolution and Contrast Enhancement (RCE) play a key role to improve the image quality then enhanced image appears more clearly than the input image (II). Resolution Enhancement (RE) and Contrast Enhancement (CE) both are important features in the image enhancement process to get more details from the II[2][3].

There are various methods have been developing RCE recently [4]. Hassan Demirel and Gholam Reza Ambarjafari proposed the method [5] of Image RE by Discrete Wavelet Transform(DWT). That method decomposed images using DWT, and high-frequency components are cubic interpolated. In that method, the noise has a significant effect due to the downsampling of DWT and causing blurring due to bicubic interpolation. TV Hyma Lakshmi et al. proposed DWT and GMM interpolated satellite image RCE technique [6] which reduces the blurring effect due to the usage of the GMM interpolation. Hassan Demirel and GholamrezaAnbarjafari proposed the method of image RE with Stationary Wavelet Transform (SWT) and DWT [7]. That method decomposed the image with SWT, and edge pixels are bi-cubic interpolated gives better results than DWT and bicubic interpolation. TV Hyma Lakshmi et al. proposed NDWT and GMM interpolated satellite image enhancement technique [8] which reduces the blurring effect due to the usage of the GMM interpolation and give superior results than before existed methods, proved with quantitative and qualitative results. CE is increasing the quality of the image to a better level for feature extraction or image data interpretation. CE can be divided into two basic groups: spatial domain and transformed domain. Spatial domain techniques are worked on pixels in the image space and transform domain techniques are worked on the transform of the image. Histogram equalization (HE) is a contrast adjustment [9] of the image using the histogram in image processing. HE adjusts the intensities of the pixels in the entire image to improve the clarity of the image. HE works best on an over or underexposed image, which has a narrow contrast range. Since the HE is applied to the whole image, the local details are not enhanced effectively. To overcome these drawbacks, local histogram equalization (LHE) based methods are proposed. Huang Lidong proposed [10] CLAHE-DWT method which is one of the CE methods and uses the combination of both DWT and CLAHE. The limitations of CLAHE can be minimized by the CLAHE-DWT method. TV HymaLakshmi et al. proposed SWT and GMM interpolated satellite image RE technique along with the CLAHE [11] which reduces the blurring effect due to the usage of the GMM interpolation and CLAHE proved with quantitative and qualitative results. In this paper, we introduce a new RCE which can improve resolution, the contrast of the image, avoid over enhancement, reduce the noise effects and also improve the execution speed.

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II. RELATED WORK

A. *Lifting Wavelet Transform*

Lifting wavelet transform (LWT) was introduced by WimSweldens. It factorizes orthogonal and biorthogonal wavelet transforms into lifting operators. The number of operations is reduced by 2 as sub-sampling operations are factorized even and odd samples.

Border treatments are reduced and it is called a Para-unitary implementation filter bank. Hence the speed of operation is increased drastically due to the reduction of the computation complexity. This is the main advantage of the LWT [12].

B. *CLAHE*

The procedure of CLAHE is given below:

1. Divide the II into sub-blocks (SBs).
2. Set the clip limit, clip the histograms above clip limit and redistribute to other SBs.
3. Apply histogram equalization to each SB.
4. Interpolate the neighboring SB.

The selection of SB size and clip limit is crucial for CLAHE because these parameters mainly control image quality. These parameters of CLAHE [13] are determined based on image entropy. Image entropy is proportional to the distribution of histogram. Selection of SB size and clip limit as follows.

1. Set SB size as [8 8], vary the clip limit and apply CLAHE to the input image.
2. Find entropy of CLAHE output, maximum entropy gives the best clip limit.
3. Update the above-obtained clip limit, now vary the SB size from [2 2] to [32 32].
4. Repeat step 2, maximum entropy gives the best SB size.
5. Update the SB size with the value obtained above and performs the CLAHE with these parameters.

Discrete entropy is defined as [8] follows

$H(x) = -\sum_{i=1}^{N} P(x_i) log_2 p\,(x_i)$ (1)

CLAHE-DWT: This method uses the combination of CLAHE and DWT to eliminate the drawbacks of CLAHE. By applying CLAHE to detailed coefficients can reduce the noise. The Weighted average of the original image and reconstructed image alleviates the contrast overstretching. Pixels with higher intensities are enhanced less because of the proportionality of the weighting factor with pixel intensities. Choosing of the weighting factor has significance and it is selected based on local entropy increment (LEI).

This proposed method uses the combination of LWT-SWT for RE and CLAHE-SWT for CE. First, II of size [256×256] is decomposed using both DWT and SWT using Haar mother wavelet to get the low-frequency components and high-frequency components individually. The Haar wavelet is the simplest wavelet of all other wavelet families in terms of the computation of wavelet coefficients.

C. *Gaussian Mixture Model*

Edge pixels restoration is a tough task while interpolation of images while reproducing high-resolution images from low-resolution images. However, Bicubic interpolation gives sharper edges than bilinear and nearest neighbor interpolation it still suffers from blurred edges. Hence, we applied the Gaussian Mixture (GM) interpolation to get sharper edges. In our method, II is decomposed by DWT into different sub-band images having high variance and low variance sub-band images. The high variance or high-frequency pixels (edges) are interpolated with the highest probability of covariance of M pixels and mean of the pixels ∑i to get sharper edges, better PSNR, and QI than bicubic interpolation. It is computed as a weighted sum of M Gaussian densities. It is computed as:

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

Where x depends on the number of dimensions in the image data and it is a continuous-valued data vector.

w_i is the mixture weight and i = 1,2,3,…,M.

$g(x|\mu_i, \Sigma_i)$ Gaussian densities. Whereas i=1,2,…,M. and it is calculates as

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

Whereas μ_i is a mean vector and it is given as $\mu i = \frac{\sum_{i=1}^{n} x_i}{n}$ and Σ_i is covariance matrix and it is given as $\Sigma_i = \frac{\sum_{i=1}^{n}(x_i - \overline{x})}{n-1}$

λ is the set of $P_{i,}$ μ_i and Σ_i

Where P_i weights of the individual components [14].

III. PROPOSED METHOD

This proposed method uses the LWT-SWT to get RE and CLAHE-SWT to achieve CE. First, II (Fig.2a) of size [256×256] is decomposed by applying LWT and SWT using Haar wavelet into L-L, L-H, H-L and H-H sub-band images. L-L is the low-frequency information obtained by applying low pass filters and it is the approximation of original image with half size of the original image. L-H, H-L and H-H are the vertical, horizontal and diagonal information respectively. LL1, LH1, HL1 and HH1 are the sub-band images obtained after applying SWT. The SWT is used to reduce the pixel loss and high frequency sub-bands of LWT are interpolated with factor 2 with the help of GMM interpolation. GMM interpolation method uses the highest probability intensity values based on the covariance matrix and mean vector. This method gives excellent results both in calculation speed and quality of transformed image. Interpolation increases the number of pixels in a given image. High frequency sub-bands of SWT and interpolated sub-bands of LWT are combined. By taking the Inverse LWT of low frequency sub-band and new sub-bands we get the high resolution image with size [512×512].Now the image is resolution enhanced but contrast of image is still poor .To improve the contrast of image ,CLAHE techniques is used on the resolution enhanced image. First Resolution enhanced image is given to SWT. SWT is preferred because of its self-property of no down sampling and LWT improves the speed of operation, this is the main advantage of SWT over DWT in terms of pixel loss. Now, CLAHE is applied to low frequency sub-band. This is because high frequency sub-bands contains edges, most of noise and by applying CLAHE to these sub-bands also causes noise increment. Hence, CLAHE is applied to low frequency sub-bands only. By taking the Inverse transform of CLAHE applied sub-band and high frequency bands we get high contrast image with size [512×512].On taking the average of low contrast image and resultant of Inverse transform noise can be further be reduced.

Finally resultant images are both RE and CE images shown in fig 2 and 3. Proposed techniques is compared with existing techniques with visual results and quantitative results in table 1 and 2 using noise estimation and peak signal to noise ratio. For the estimation of noise, noise is added to input image with mean zero and with a variance of 2.56. Table1. give the PSNR and NE values of gray scale satellite image.

IV. RESULT ANALYSIS

In this experiment, proposed algorithm has been used for analysis of satellite images. The performance of proposed method is compared with (2b) DWT and bicubic interpolated image, (2c) DWT and GMM interpolated image, (2d) SWT and bicubic interpolated image, (2e) SWT and GMM interpolated image (2f) Proposed Method with different parameters Peak Signal to Noise Ratio (PSNR) and Noise Estimation (NE). Both visual results and quantitative results are confirming the superiority of the proposed method. Figures.2, 3 and Table.1 show the superiority of the proposed method over the previously existing image enhancement techniques.

A. *Peak Signal to Noise Ratio (PSNR)*

It is the ratio between the maximum possible signal powers to the noise power. Here noise means mean of square of error between input image and enhanced image and it is called as mean square error (MSE).

B. *Noise Estimation (NE)*

It is used to measure the noise amplification during the process of RE and CE (12). For the estimation of noise, noise is added to input image with mean zero and with a variance of 2.56. Table.1 give the PSNR and NE values of gray scale satellite image. Pictorial and quantitative results (PSNR and NE) show that proposed method performs better than the previous techniques.

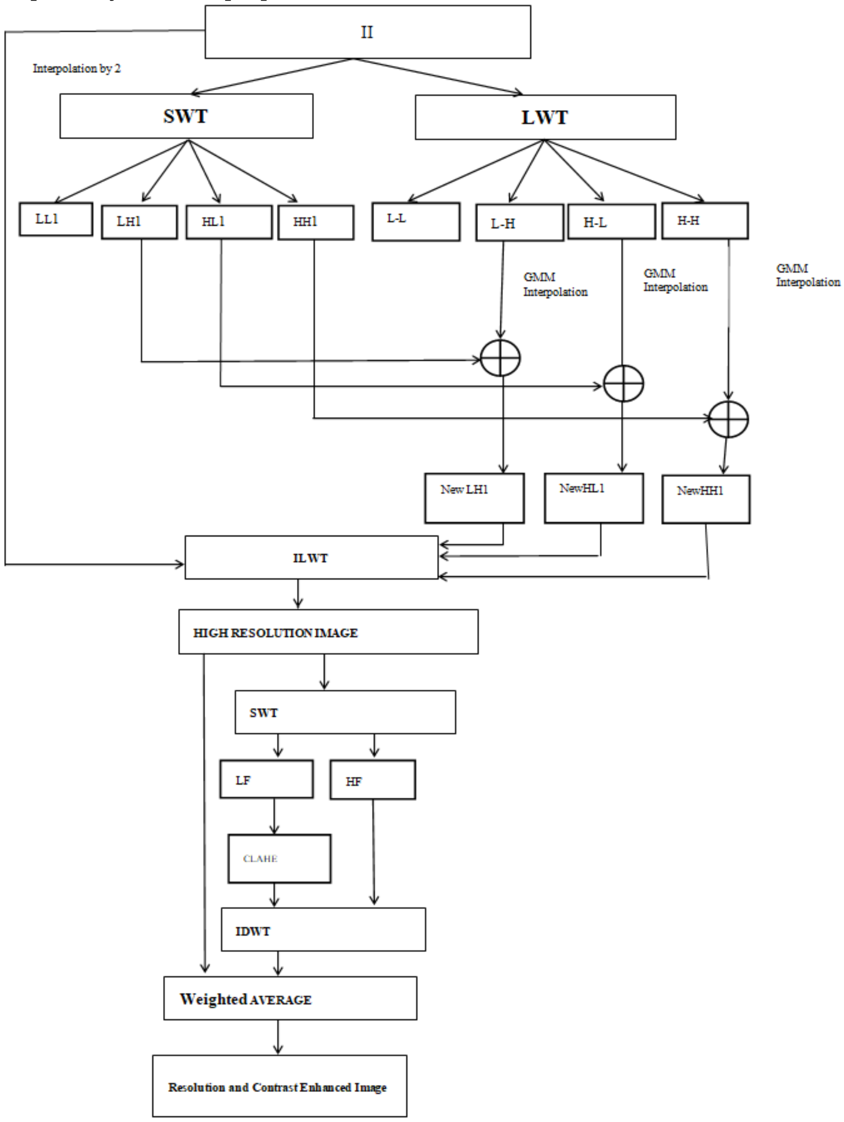

Figure.1 Proposed methodFlowchart

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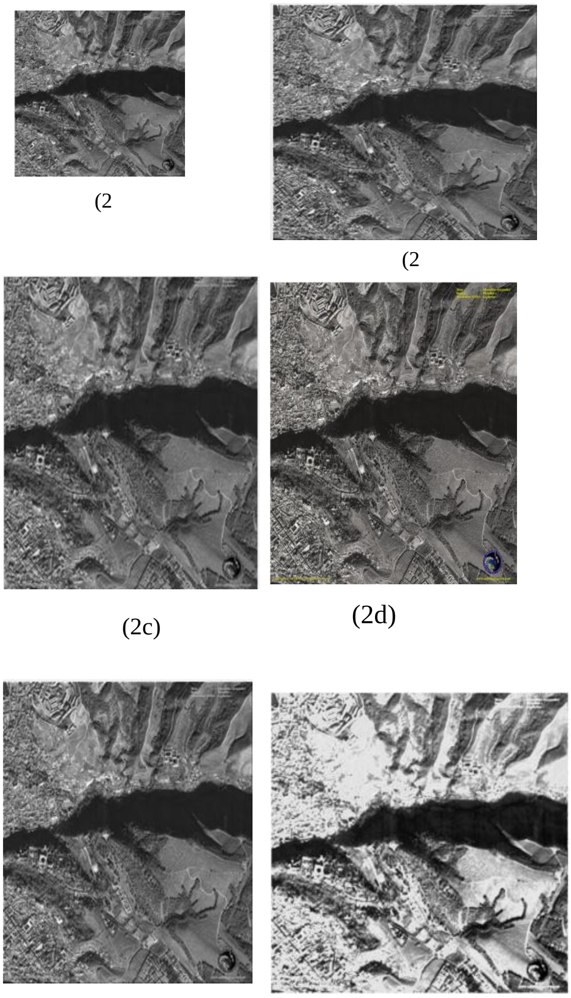


(2 (2

(2c) (2d)

(2e) (2f)

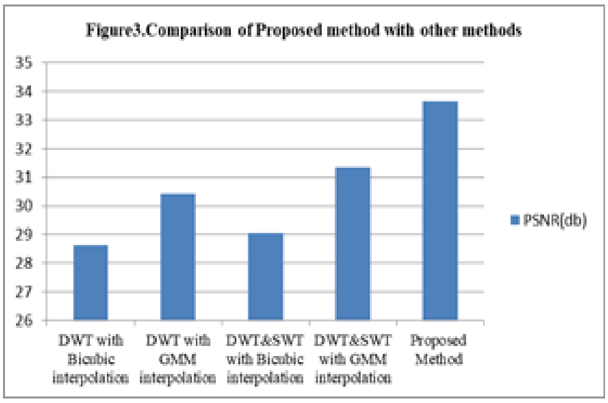
Figure 2.Satellite Image (2a) Low Resolution Input Image, Resolution Enhanced Images using (2b) DWT and bicubic interpolated image., (2c) DWT and GMM interpolated image, (2d) SWT and bicubic interpolated

V. CONCLUSION

In this paper, we proposed a resolution and contrast enhancement technique using SWT, LWT, GMM, and CLAHE. We tested this technique on the satellite image and proved that our proposed method gives superior results than the other existing techniques in pictorial results and quantitative results. Due to the usage of GMM interpolation get sharper edges and smoother details. In GMM interpolation the intensity value for an interpolated pixel is assigned with the highest probability value from the mean and standard deviation vectors of sixteen neighboring pixels instead of the weighted average of sixteen neighboring pixels in bicubic interpolation. After resolution enhanced, image is also contrast enhanced so that we get superior results in both quantitative and visual results.

Table1.Comparison of Proposed method with other methods

	PSNR(db)	NE(σ)
DWT with Bicubic interpolation	28.64	0.266
DWT with GMM interpolation	30.44	0.2582
DWT&SWT with Bicubic interpolation	29.05	0.2458
DWT&SWT with GMM interpolation	31.34	0.22613
Proposed Method	33.66	0.2063



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