Application of Framelet Transform and Singular Value Decomposition to Image Enhancement

Sulochana Subramaniam[1], Vidhya Rangasamy[1], Vijayasekaran Duraisamy[1], and Mohanraj Karuppanan[2]
[1]Institute of Remote Sensing, Anna University, India
[2]Software Engineer, Wipro Technologies, India

Abstract: *In this paper, a new satellite image enhancement technique based on framelet transform and Singular Value Decomposition (SVD) has been proposed. Framelet transform is used to decompose the image into one low frequency subband and eight high frequency subbands. The enhancement is done with regard of both resolution and contrast. To increase the resolution, low and high frequency subbands have been interpolated. In intermediate stage, estimating high frequency subbands has been proposed to achieve sharpness. All the subbands are combined by inverse framelet transform to get the high resolution image. To increase the contrast, framelet transform is combined with SVD. Singular values of the low frequency subband are updated and inverse transform is performed to get the enhanced image. The proposed technique has been tested on satellite images. The quantitative measures such as Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index Measure (SSIM), Universal Quality Index (UQI), Entropy, Quality_ Score are used and the visual results show the superiority of the proposed technique over the conventional and state-of-art image enhancement techniques. The time complexity indicates the proposed image enhancement is suitable for further image processing applications.*

Keywords: *Generalised histogram equalization, SVD, discrete wavelet transform, framelet Transform, PSNR, SSIM, UQI.*

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1. Introduction

Image Enhancement is a fundamental pre-processing step to enhance the visual quality of an image as well the specific features for further applications. Objects and boundaries in satellite images are not sharp, and it can be used to distinguish and delineate land cover features. So it is essential to have the image with clear and well defined boundaries of an object. The quality of the displayed image is influenced by many factors such as resolution and contrast. The source may be a low resolution camera and difference in luminance reflected from two adjacent surfaces. The problem is to increase the spatial resolution and optimize the contrast of an image in order to represent all the information in the input image. The most commonly practiced techniques for image resolution enhancement is an interpolation. There are three well known interpolation techniques namely nearest neighbour interpolation, Bilinear interpolation, Bicubic and cubic spline interpolation. In image resolution enhancement by using interpolation causes loss of high frequency components which is due to the over smoothing. For the contrast enhancement some basic operations [3, 10, 18, 19, 20] like General Histogram Equalization (GHE), Local Histogram Equalization (LHE), Brightness Preserving Dynamic Histogram Equalization (BPDHE) GHE and Spatially Weighted Histogram Equalization (SWHE) were used in literature. GHE is a simple method for contrast enhancement, which consists of generating an output image with a uniform histogram. In image processing the idea of equalizing a histogram, is to stretch the original histogram using the entire range of discrete levels of the image. GHE is a commonly used for image contrast enhancement since it is computationally fast and simple to implement. One of the disadvantages of GHE is that the information laid on the histogram or probability distribution function is lost. Recently wavelet theory [12] has brought us new algorithms and methods in image processing. Wavelet transform has the ability of multiresolution and representation of an image with flexible localization in both time and frequency domains are applicable to enhancement in image processing.

The most commonly used wavelet transform is critically sampled Discrete Wavelet Transform (DWT) in image enhancement applications [4, 5, 7]. DWT is not good when isolation of directional features which is not adjusted in horizontal and vertical directions. The discrete wavelet transform is shift variant due critical sub sampling. This can lead to small shifts in the input waveform causing large changes in the wavelet coefficients, large variations in the distribution of energy at different scales and possibly large changes in reconstructing waveforms.

Remote sensing images are frequently tempted by low resolution, blurry quality and distortion due to camera viewpoints. Image enhancement is difficult in noisy images sometimes leads to missing true edges, false edge detection and localization. Though much advancement made in image enhancement, applying and finding an efficient method of enhancement in remote sensing images is a major challenge for researchers in the field of satellite image processing. Even though these existing enhancement techniques bring about good results, application of wavelets in remote sensing image enhancement is limited. Recently framelet transform has been used many image processing applications such as super resolution [2] image fusion [17]. To eliminate the impacts on satellite images with classical image enhancement algorithms and improve precision of edge locating, an effective image enhancement algorithm based on Framelet transform combined with suitable interpolation method is proposed.

The Framelet Transform (FRT) [1] is similar to wavelets but has some differences. Framelets has two or more high frequency filter banks, which produces more subbands in decomposition. This can achieve better time, frequency localization ability in image processing. There is redundancy between the framelet subbands, which means a change in coefficients of one band, can be compensated by other subbands coefficients. After framelet decomposition, the coefficient in one subband has correlation with coefficients in the other subband. This signifies that alterations on one coefficient can be counterbalanced by its related coefficient in the reconstruction stage which produces less noise in the original image. A tight frame filter bank provides symmetry and has a redundancy that allows for approximate shift invariance [6]. This leads to clear edges with effective denoising which is lacking in critically sampled discrete wavelet transform.

The organization of this paper is as follows, section 2 gives the data description and proposed algorithm. Experimental results are discussed in section 3 and quality metrics introduced in section 4. Finally conclusion is drawn in section 5.

2. Data Description and Proposed Algorithm

Satellite images used in this work as LANDSAT–MSS, LANDSAT-TM, LANDSAT -ETM+ and LISS-III specifications are given in Table 1.

Table 1. Specification of remote sensing images.

S.No	Satellite	Imaging Sensor	No. of Bands	Spatial Resolution	Area
1.	LANSAT	MSS	4	60m	Dindigal (Tamil Nadu)
2.	LANSAT	TM	1 to 5 &7 6(PAN	30m 120m	Dindigal (Tamil Nadu)
3.	LANSAT	ETM	1to7 8(PAN	30m 15m	Dindigal (Tamil Nadu)
4.	IRS P6	LISS III	4	23.5m	Dindigal (Tamil Nadu)

Our proposed method has two important parts.

1. Resolution enhancement (framelet transform with interpolation).
2. Contrast enhancement (framelet transform combined with Singular Value Decomposition (SVD)).

1. Framelet Transform is used to decompose the input image (J) into sub-band images.
2. Apply suitable interpolation to high frequency subbands and one low frequency subband images of Framelet transform of images.
3. Difference image is obtained by subtracting interpolated low frequecy subband of framelet transform and add the interpolated high frequency subbands of framelet transform with difference image.
4. Lowpass band is the illumination information of low resolution image. Instead of using lowpass sub-band, which contains less information than the original image we are using input image itself.
5. Inverse framelet transform is applied to get high resolution image (I).
6. High resolution image (I) is first processed by using GHE, the resultant image is $\bar{I}$.
7. (I & $\bar{I}$) both images are transformed by framelet transform into low and high frequency subbands.
8. The correction coefficient for the singular value matrix is calculated by using the following Equation (1)

$$\xi = \frac{\max(\Sigma LL_{\bar{I}})}{\max(\Sigma LL_{I})} \tag{1}$$

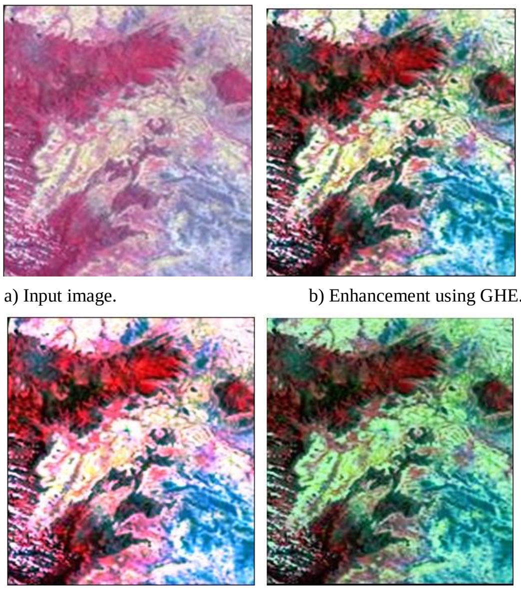
Where, $\sum LLI$ is the LL singular value matrix of the input image and $\sum_{LL_{\bar{I}}}$ is the singular value matrix of the output of the GHE.

9. The new singular value matrix of Lowpass (LL) image and new Lowpass (LL) image is composed by

$$\begin{aligned} \bar{\Sigma}_{LL_I} &= \xi \Sigma_{LL_I} \\ \overline{LL}_I &= U_{LL_I} \bar{\Sigma}_{LL_I} V_{LL_I} \end{aligned} \tag{2}$$

10. Subband images are recombined by applying inverse framelet transform to generate the resultant equalised image $\hat{I}$ and the enhanced images are shown in Figures 1, 2, 3, and 4.

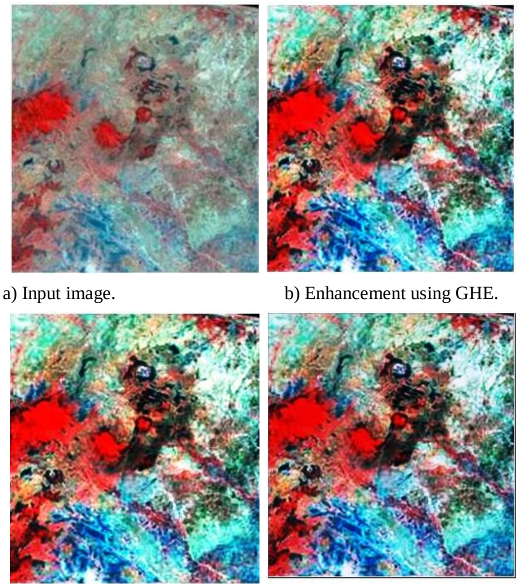
$$\bar{I} = (\overline{LL}_I, LH1_I, LH2_I, H1L_I, H1H1_I, H1H2_I, H2L_I, H2H1_I, H2H2_I) \tag{3}$$



a) Input image. b) Enhancement using GHE.

c) Enhancement using DWT-SVD. d) Enhancement using FRT-SVD.

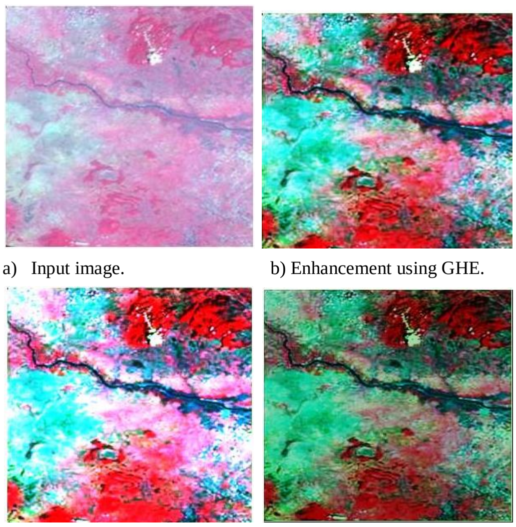
Figure 1. LANDSAT-MSS_60m resolution.



a) Input image. b) Enhancement using GHE.

c) Enhancement using DWT- SVD. d) Enhancement using FRT- SVD.

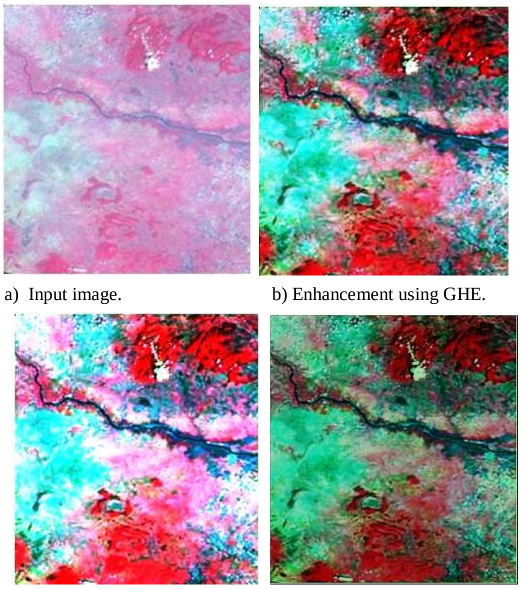
Figure 2. LANDSAT-TM_30m resolution.



a) Input image. b) Enhancement using GHE.

c) Enhancement using DWT-SVD. d) Enhancement using FRT-SVD.

Figure 3. LANDSAT-ETM+_30m resolution.



a) Input image. b) Enhancement using GHE.

c) Enhancement using DWT-SVD. d) Enhancement using FRT-SVD.

Figure 4. LISS III _23.5m resolution.

3. Experimental Results

Our proposed algorithm was implemented using Matlab 7.0 The framelet used in our algorithm has one low pass filter and two high pass filters. Satellite images with different resolutions were used to test our proposed method. For contrast enhancement we have used five interpolation methods such as nearest neighbour, bilinear, bicubic, cubic spline and Lanczos interpolation and corresponding Peak Signal-to-Noise Ratio (PSNR) values were calculated shown in Table 2. Lanczos interpolation gives better outcomes compared to other four interpolation methods which are selected for interpolation and the resultant image is used for contrast enhancement.

Contrast enhanced images have been equalized by GHE, DWT-SVD and proposed method such as framelet transform. The quality of the visual results indicates that the proposed equalization gives good results compared with GHE and DWT-SVD. To start our analysis, for each image, we compute the brightness (i.e., the mean) and contrast (i.e., the standard deviation) of the original and the output images obtained by the proposed methods shown in Table 3. By observing the absolute difference between the value of the brightness in the original and processed images (i.e., the brightness preservation), we state that the images produced by our proposed methods are better in preserving the brightness of the original images. We perform a similar analysis by observing the contrast values; we state that the images produced by the GHE methods give good results. Observing brightness and contrast our proposed methods produces good results.

Table 2. PSNR Values for satellite images with different interpolation.

Interpolation Method	LANDSAT MSS	LANDSAT TM	LANDSAT ETM+	LISS III
Nearest Neighbour	25.05	26.21	26.78	27.09
Bilinear	27.40	27.95	28.12	28.20
Bicubic	28.36	28.90	29.35	29.75
Cubic spline	29.68	30.12	31.24	31.98
Lanczos	32.45	32.89	33.98	34.22

Table 3. Brightness and contrast of satellite images with different resolution.

Image	Method	Brightness	Contrast
LANDSAT MSS	INPUTIMAGE	175.22	70.21
	GHE	181.42	80.38
	DWT-SVD	183.93	75.64
	FRT-SVD	189.20	82.18
LANDSAT TM	INPUT IMAGE	186.63	74.03
	GHE	179.45	81.30
	DWT-SVD	186.56	82.14
	FRT-SVD	190.71	84.68
LANDSAT ETM+	INPUTIMAGE	189.10	77.32
	GHE	192.56	79.61
	DWT-SVD	193.87	80.55
	FRT-SVD	195.20	84.18
LISS III	INPUTIMAGE	188.22	79.34
	GHE	191.42	81.70
	DWT-SVD	187.93	82.67
	FRT-SVD	198.20	86.89

4. Image Quality Metrics and Complexity Analysis

Image Quality is a characteristic of an image that measures the perceived image degradation. Quality assessment methods can be broadly classified into two categories: Full Reference Methods (FR) and No Reference Method (NR). In FR, the quality of an image is measured in comparison with a reference image which is assumed to be perfect in quality. NR methods do not employ a reference image. The image quality metrics [7, 8, 15, 16, 17, 18] were considered and implemented here fall in the FR category and entropy [11]] and Quality _Score [17] was calculated NR method. PSNR, Structural Similarity Index Measure (SSIM) and Universal Quality Index (UQI), Entropy and (Quality-Score) were used to evaluate the efficiency of the proposed method is shown in Table 4. which shows that the proposed method yields better results than other existing methods. The elapsed time was counted using Matlab (*tic*) ad (*toc*) functions. The time complexity is less than conventional image enhancement method. This analysis also proves the validity and feasibility of our proposed method. This new approach can be used in further image processing applications.

Table 4. Quality metrics for different satellite images.

IMAGE	METHOD	PSNR	UQI	SSIM	Entropy	(Quality_ Score)
LANDSAT MSS	GHE	23.1085	0.9341	0.9196	4.1245	6.3450
	DWT	23.4030	0.9426	0.9095	4.6789	6.8145
	FT	25.3061	0.9556	0.9467	5.1789	7.1230
LANDSAT TM	GHE	24.1234	0.9345	0.9225	4.8901	6.5671
	DWT	25.4521	0.9426	0.9356	5.3678	6.9346
	FT	26.6530	0.9512	0.9479	6.3456	7.3206
LANDSAT ETM	GHE	25.6780	0.9512	0.9499	5.4901	7.8654
	DWT	26.1560	0.9567	0.9500	5.9025	8.1934
	FT	26.9210	0.9598	0.9559	6.2908	8.6267
LISS III	GHE	26.6570	0.9654	0.9523	6.5567	7.6942
	DWT	27.3458	0.9678	0.9612	7.2780	8.4590
	FT	28.2456	0.9705	0.9790	7.9562	8.9349

5. Conclusions

In this paper a new image enhancement technique was proposed based on framelet transform and singular value decomposition SVD. The proposed technique decomposed the input image into one approximation and eight detailed subbands. To increase spatial resolution framelet transform subbands were interpolated using different interpolation methods and estimated high frequency subbands were combined with input low resolution input image. Inverse transformed high resolution image was given to next level contrast enhancement. Then SVD of the low pass (LL) band is updated and inverse transform was performed to get the enhanced image in terms of resolution and contrast.

The proposed techniques were compared with the DWT-SVD and GHE. Brightness and contrast was calculated which shows the superiority of the proposed method over conventional methods. Finally quantitative measures (PSNR, SSIM, UQI, Entropy and Quality_Score) were calculated for evaluating the performance of the proposed methods. The time complexity of the proposed approach is good compared to other methods.

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Vidhya Rangasamy is an Associate professor at the Institute of Remote Sensing, Anna University, Chennai. She completed her B.E in Civil Engineering with Honors, M. Tech and Ph.D in Remote Sensing. She has 25 years of experience in teaching and Research. Her field of interest is in Remote Sensing data analysis, application to water resources.

Sulochana Subramaniam is a Research scholar at Institute of Remote Sensing (IRS), Anna University, Chennai, India. She has completed M.Sc. physics and M. Tech in Remote Sensing and Wireless Sensor Networks. Her research interest includes image processing using wavelets, remote sensing, GIS and machine learning concepts.

Vijayasekaran Duraisamy is a Research fellow at Institute of Remote sensing Anna University; he completed his Bachelor's degree in Botany and M.Sc in Remote sensing. He has 5 years of experience in research projects related to remote sensing and GIS. His field of interest includes remote sensing invasive ecology, Socio economic impacts of alien plants.

Mohanraj Karuppanan is a Technical lead in Wipro Technologies, Bangalore, Karnataka, India. He completed B.E in Electrical Engineering and M.E in Computer Science. His research interest includes image processing, computer networks and telecom management solutions.