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SATELLITE IMAGE RESOLUTION ENHANCEMENT USING MODIFIED BICUBIC-GAUSSIAN INTERPOLATION

Dr. T. V. Hyma Lakshmi, Assistant Professor, Dept. Of ECE, S R K R Engineering College.

Abstract
Satellite Images play an important role 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 modified Gaussian-Bicubic interpolation to obtain sharper edges and smoother details to improve the quality of the image. The kernel consists of Gaussian filter coefficients of sixteen neighboring pixels instead of weighted sum of neighboring pixels such as bicubic or bilinear interpolations. DWT image decomposition and modified Gaussian-Bicubic 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.

Keywords:
Bicubic-Gaussian interpolation, Resolution enhancement, Satellite images, Wavelet Transforms.

I. Introduction

Satellite images (SI) are being used in diverse fields such as geographical information systems, forecasting the weather condition, astronomy, geological sciences, disaster management, rescue planning etc. [1]. The major issues in using unprocessed SI are resolution, contrast and brightness of the images. SI with high resolution are always preferred for obtaining better results in almost all the remote sensing applications, artificial intelligence, road safety systems, etc. [2 -4].
Further, preserving the edges present in an image is a very important aspect in the process of image interpolation while enhancing the resolution of the image. The higher frequency elements or edges might be altered [3,4] during the interpolation process due to the smoothening effect. Wavelets can preserve the edges by decomposing the image into detailed and approximate coefficients for the process of interpolation to get the better results in resolution enhancement (RE) process [5]. Recently several wavelet based decomposition and bicubic interpolation techniques for RE of SI are proposed [6]. However the bicubic interpolation give the best results than bilinear and nearest neighbour interpolation, still bicubic interpolation suffering from the blurring effect of the edges in the interpolation process due to weighted average of the sixteen neighbouring pixels [7-8]. To reduce the blurring effect by getting sharper edges smoother details Gaussian interpolation method is proposed. The proposed DWT-Gaussian interpolation method is compared with bilinear interpolation, bicubic interpolation, Gaussian interpolation and DWT-Bicubic interpolation with qualitative and quantitative results.

II. Proposed Method

Interpolation is the process of adding extra rows and columns of pixels to increase the resolution of the image [9]. The basic interpolation technique replicates the rows and columns number of times based on the desired resolution enhancement. However, this process has less complexity and less computation time results obtained using this process is satisfactory, but not efficient. The techniques like bilinear interpolation [10] and bicubic interpolation [11] use linear functions to interpolate the additional pixels [12]. The proposed Gaussian interpolation technique uses Gaussian smoothing to

estimate the pixels that need to be interpolated. For each pixel to be interpolated a 4x4 window of pixels is extracted and Gaussian smoothing is applied. The smoothed pixel is then used to interpolate the input pixels.
Applying interpolation on the image pixels directly may lead to blurring. In order to overcome this drawback, DWT and Gaussian interpolation based technique is implemented. In this technique, DWT is used to decompose the input image. The approximate, horizontal, vertical and diagonal coefficients are interpolated with Gaussian interpolation and then inverse wavelet is used to reconstruct the image. This process preserves the edges present in the image thereby improving the quality of interpolation. The well –known interpolation methods are the nearest neighbour, bilinear and bicubic. Bicubic interpolation gives the best results among these three interpolation techniques. However bicubic interpolation suffers from the blurring effect of the edges in the interpolation process due to its weighted average of the sixteen neighboring pixels. To overcome this loss, to get sharper edges and smoother details modified Gaussian-bicubic interpolation is proposed. This proposed Gaussian based interpolation RE method improves the resolution of the image by two times by using a combination of DWT and Gaussian based bi-cubic interpolation. This process is presented in the figure 1.
In this method, the low resolution satellite image is decomposed using DWT. This produces the approximate, horizontal, diagonal and vertical image coefficients namely LL, LH, HL and HH. These coefficients are given as an input to the Gaussian interpolation algorithm. This step doubles the size of the wavelet coefficients. Wavelet reconstruction is applied on the modified coefficients to obtain the resolution enhanced image.

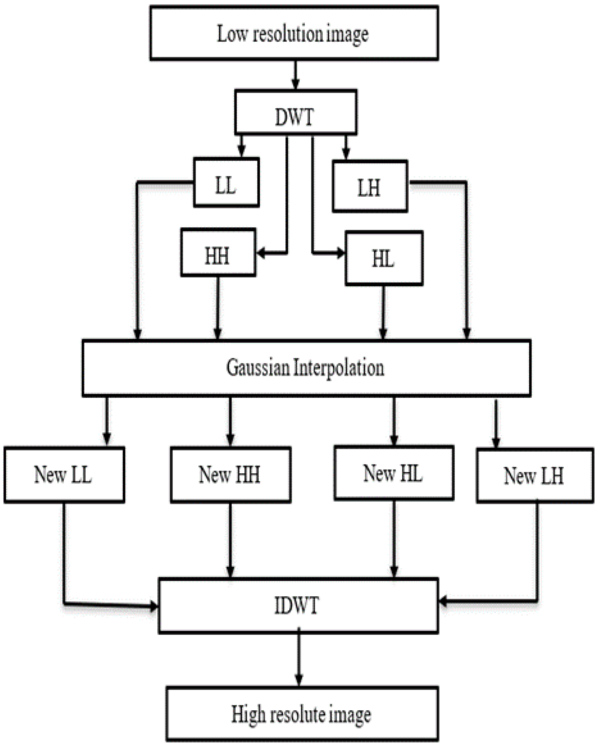

Figure 1: Proposed DWT and GAUSSIAN interpolation based image resolution enhancement

The Gaussian smoothing operator [13] is a 2-D convolution operator that is used to smoothening the images and to reduce the noise. It means it is similar to mean filter, but it is modified to bicubic-Gaussian function which gives the sharper edges and smoother details when it is applied to interpolate the decomposed sub-band images separately. This digitized modified bicubic-Gaussian kernel has applied to LL, HH, HL and LH sub-bands separately to obtain the new LL, new HH, new HL and new LH sub-bands. The Gaussian distribution in 1-D has the form:

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$$G(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}} \quad (1)$$

where ‘σ’ is the standard deviation of the distribution[14]. We have also assumed that the distribution has a mean of zero (i.e. it is centered on the line x=0). The distribution is illustrated in Figure 2.

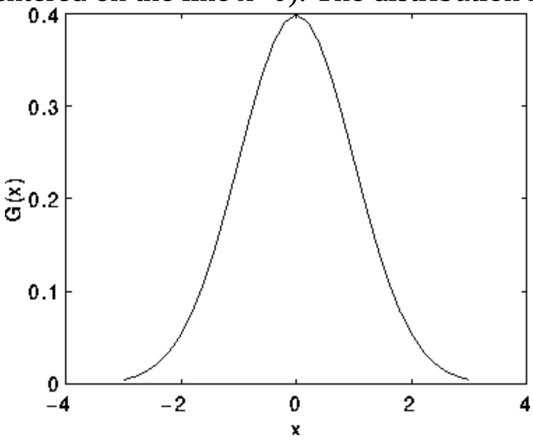

Figure 2: One-Dimensional Gaussian distribution with mean 0 and σ =1

In 2-D, an isotropic (i.e. circularly symmetric) Gaussian has the form:

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (2)$$

This distribution is shown in Figure 3.

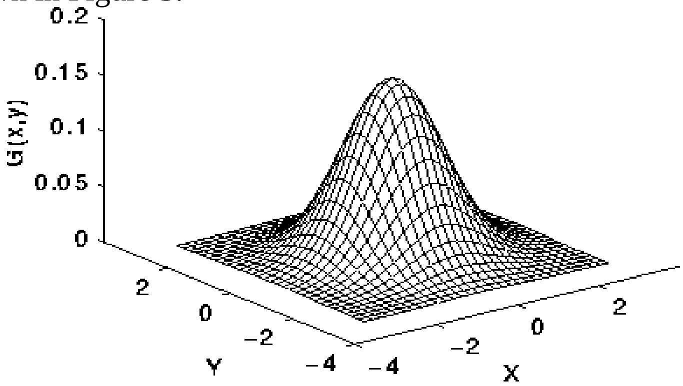

Figure 3. Two-Dimensional Gaussian distribution with mean (0,0) and σ =1

The idea of Gaussian smoothing is to use this 2-D distribution as a `point-spread' function, and this is obtained by convolution. Since the image is stored as a collection of discrete pixels we need to produce a discrete approximation to the Gaussian function before we can perform the convolution. In theory, the Gaussian distribution is non-zero everywhere, which would require an infinitely large convolution kernel, but in practice it is effectively zero more than about three standard deviations from the mean, and so we can truncate the kernel at this point. Table.1 shows a suitable integer-valued convolution kernel that approximates a Gaussian with a ‘σ’ of 1.0. It is not obvious how to pick the values of the mask to approximate a Gaussian. One could use the value of the Gaussian [15] the center of a pixel in the mask, but this is not accurate because the value of the Gaussian varies non-linearly across the pixel. We integrated the value of the Gaussian over the whole pixel (by summing the Gaussian at 0.001 increments). The integrals are not integers: we rescaled the array so that the corners had the value 1. Finally, the 273 is the sum of all the values in the mask.

Table1: Discrete approximation to Gaussian functions with σ=1.0

$\frac{1}{273}$	1	4	7	4	1
	4	16	26	16	4
	7	26	41	26	7

	4	16	26	16	4
	1	4	7	4	1

Once a suitable kernel has been calculated, then the Gaussian smoothing can be performed using standard convolution methods. The convolution can be performed fairly and quickly since the equation for the 2-D isotropic Gaussian shown above is separable into x and y components. Thus the 2-D convolution [16] can be performed by first convolving with a 1-D Gaussian in the x direction, and then convolving with another 1-D Gaussian in the y direction. (The Gaussian is in fact the only completely circularly symmetric operator which can be decomposed in such a way.) Table2 shows the 1-D x component kernel that would be used to produce the full kernel shown in Table1 (after scaling by 273, rounding and truncating one row of pixels around the boundary because they mostly have the value 0. This reduces the 7x7 matrix to the 5x5 shown above.). The y component is exactly the same but is oriented vertically.

Table2: One of the pair of 1-D convolution kernels used to calculate the full kernel (shown in Table 1)

0.006	0.061	0.242	0.383	0.242	0.061	0.006

A further way to compute a Gaussian smoothing with a large standard deviation is to convolve an image several times with a smaller Gaussian. While this is computationally complex, it can have applicability if the processing is carried out using a hardware pipeline. If the Gaussian interpolation is applied to the entire image, causes the blurring effect and loss of the edges. To overcome the blurring effect and preserve the edges, interpolation is applied to the DWT decomposed sub-band image coefficients. DWT decomposed image sub-bands namely LL, LH, HL and HH. HH, HL and LH sub-bands consist of detailed coefficients (edge information) and LL sub-band consists of approximated coefficients (low frequency components) [17]. Using the combination of Gaussian and bicubic interpolation, the following filter coefficients are designed with sigma value 0.4. The filter is used for interpolation in the proposed method is shown in Table 3.

Table3: Discrete approximation to modified bicubic-Gaussian function with ‘σ’=1.0

0.0001	0.0044	0.0044	0.0001
0.0044	0.2411	0.2411	0.0044
0.0044	0.2411	0.2411	0.0044
0.0001	0.0044	0.0044	0.0001

This method gives the sharper edges due to the interpolation of the high frequency components separately and also gives the smoother details due to the interpolation is applied on the low frequency components of the image separately. Inverse wavelet transform is applied to the interpolated sub-band images to reconstruct the image and to obtain the resolution enhanced image. This process doubles the resolution of the image. Due to this modified bicubic-Gaussian interpolation improves the quality of the image significantly and proved the superiority of this method by comparing the existing methods (bilinear interpolation, bicubic interpolation and DWT-bicubic interpolation).

Figure.4 (a) to (d) shows the input images used for the experiments. The images are captured using Google earth software. The borders between India and the neighbouring countries have been captured in the images used for the experiments. The borders between India and the neighbouring countries have been captured in images.

Figures 4 (a) and (b) show the India - Pakistan border near Atari and Parlah. Figures. 4 (c) and (d) show the India - Nepal border near Sankalpa and Gopalpur. Figure 4 represents the input images that have been resized to 320x180.

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(a) Input image 1 resized to 320x180


(b) Input image 2 resized to 320x180


(c) Input image 3 resized to 320x180


(d) Input image 4 resized to 320x180

Figures 4 (a) India - Pakistan border near Atari (b) India - Pakistan border near Parlah (c) India - Nepal border near Sankalpa and (d) India - Nepal border near Gopalpur.

The resized input images shown in Figure 4 have been given as input to image interpolation algorithms. The algorithms under experimentation are:

a) Bilinear interpolation
b) Bicubic interpolation
c) Gaussian Interpolation
d) DWT decomposition with bicubic interpolation
e) Proposed DWT decomposition with Gaussian Interpolation

Figure 8 represents the Output images for input image1 using different interpolation techniques that have been resized to 1280x720 from the size of input image 320x180.


A) → Bilinear output for input


(B) Bicubic output for input


C) → Gaussian output for input


D)DWT-Bicubic output for input


E) → DWT-GAUSSIAN output for input

Figure 8 represents the Output images for input image1 using different interpolation techniques that have been resized to 1280x720 from the size of input image 320x180.

Table 4 shows the MSE, PSNR, SSIM and UIQI values obtained by the different interpolation techniques for input image 1.

Table 4. Quality parameters for different interpolation methods for input image 1

Methods	MSE	PSNR	SSIM	UIQI
Bilinear	91.72833	28.50577	0.919798	0.999147
Bicubic	90.26099	28.5758	0.928803	0.999189
Gaussian	73.56971	29.46381	0.945164	0.99956
DWT with Bicubic	174.8528	25.70408	0.8360693	0.972923
DWT with Gaussian	41.36245	31.96474	0.947709	0.999837

Figure 9 represents the Output images for input image2 using different interpolation techniques that have been resized to 1280x720 from the size of input image 320x180.

A) Bilinear output for input image 2

B) Bicubic output for input image 2

C) Gaussian output for input image 2

D) DWT-Bicubic output for input image 2

E) DWT-GAUSSIAN output for input image 2

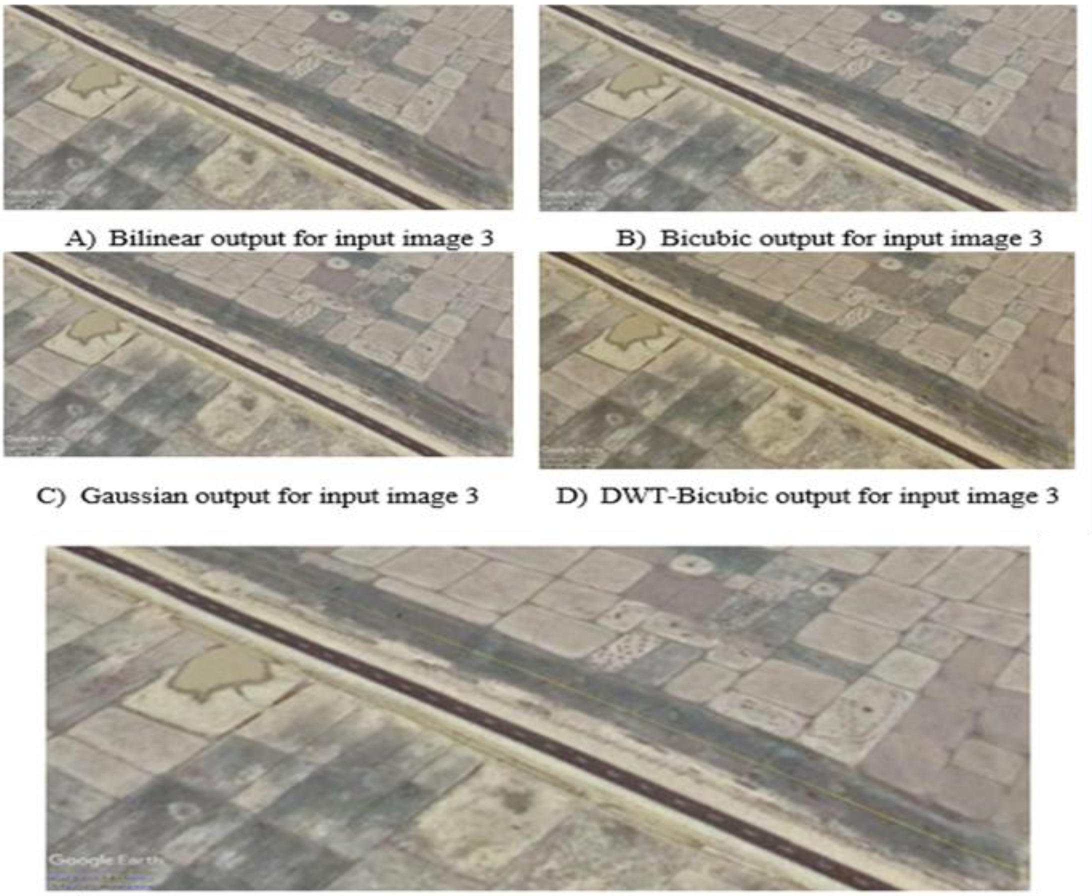
Figure 9 represents the Output images for input image2 using different interpolation techniques that have been resized to 1280x720 from the size of input image 320x180.

Table 5 shows the MSE, PSNR, SSIM and UIQI values obtained by the different interpolation techniques for input image 2.

Table 5. Quality parameters for different interpolation methods for input image 2

Methods	MSE	PSNR	SSIM	UIQI
Bilinear	125.1083	27.15794	0.919481	0.992596
Bicubic	120.3173	27.32752	0.927414	0.994792
Gaussian	95.59723	28.32635	0.946851	0.997177
DWT with Bicubic	171.1324	25.79748	0.850243	0.884627
DWT with Gaussian	51.84682	30.98358	0.944815	0.998825

Figure.10 represents the Output images for input image3 using different interpolation techniques that have been resized to 1280x720.



E) DWT-GAUSSIAN output for input image 2

Figure 10 represents the Output images for input image3 using different interpolation techniques that have been resized to 1280x720 from the size of input image 320x180.

Table 6 shows the MSE, PSNR, SSIM and UIQI values obtained by the different interpolation techniques for input image 3.

Table 6. Quality parameters for different interpolation methods for input image 3

Methods	MSE	PSNR	SSIM	UIQI
Bilinear	48.48303	31.27491	0.962084	0.999701
Bicubic	55.74	30.66913	0.955271	0.999708
Gaussian	41.4469	31.95588	0.970294	0.999863
DWT with Bicubic	174.8953	25.70302	0.863492	0.988809
DWT with Gaussian	23.41342	34.43615	0.962544	0.999944

Figure11 represents the Output images for input image4 using different interpolation techniques that have been resized to 1280x720 from the size of input image 320x180.

Figure 11 represents the Output images for input image3 using different interpolation techniques that have been resized to 1280x720 from the size of input image 320x180.

Table 7 shows the MSE, PSNR, SSIM and UIQI values obtained by the different interpolation techniques for input image 4.

Table 7 Quality parameters for different interpolation methods for input image 4

Methods	MSE	PSNR	SSIM	UIQI
Bilinear	66.46368	29.90496	0.962542	0.998721
Bicubic	68.54599	29.77098	0.961274	0.99878
Gaussian	53.41125	30.85448	0.972779	0.999363
DWT with Bicubic	174.8591	25.70392	0.839779	0.94925
DWT with Gaussian	29.01537	33.50452	0.969582	0.999767

III. Conclusion

In this method, satellite image resolution improvement is obtained by using discrete wavelet transform to decompose the image and modified bicubic-Gaussian interpolation to interpolate the coefficients. Instead of taking weighted average of the surrounding pixels, modified Bicubic Gaussian coefficients are interpolated to improve the resolution to times of the resolution of the original image. To reduce the blurring effect of the edges and to get smoother details interpolation is applied separately on decomposed sub-band images. The results proved that the proposed technique is superior to existing methods.

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Author Biography

Dr. Tirumani V Hyma lakshmi obtained Ph. D from K L UNIVERSITY on the area of Image processing, M. Tech.(ECE) from JNTUCE, Ananthapur and B.E. (ECE) from S.R.K.R.Engg college, Bhimavaram. Presently working as an Assistant Professor in S.R.K.R.Engg college, Bhimavaram. Published papers in various SCI (IET Image Processing), SCOPUS, UGC CARE1, reputed international journals and Springer conferences. She has awarded and published patents, completed various NPTEL courses, organized FDPs and various student activities as an IETE student advisor, women empowerment cell coordinator, Internal Complaint Committee member, etc. Won the Global Faculty Award. Her research interests are image processing, Radar Engineering, VLSI, etc. She has Fellow ship in ISTE and IETE.