High Resolution Satellite Image Enhancement Using Transform Techniques

Saravanakumar J and Suganya P

Abstract: Nowadays satellite images are used in many applications such as geoscience studies, astronomy, geographical information systems and defense monitoring. The major problem of these types of images is their resolution because the resolution of these images varies depends on the instrument used and the altitude of the satellite's orbit. A new satellite image resolution enhancement technique has been proposed based on the Wrapping technique of Discrete Curvelet Transform (DCvT), which represents edges better than wavelets. In this, an input image is transformed into frequency domain by applying 2D FFT. The product of image and curvelet in frequency domain is obtained and wrapped around the origin. Finally, the DCvT coefficients are generated by applying the inverse 2D FFT to the wrapped data. The proposed technique is tested on satellite benchmark images. The quantitative measures (peak signal-to-noise ratio, mean absolute error and mean square error) and visual results show the superiority of this technique over the other image resolution enhancement techniques.

***Index Terms*- Curvelet Transform, Discrete wavelet transform (DWT), interpolation, Peak signal-to-noise ratio (PSNR), Satellite image resolution enhancement.**

I. INTRODUCTION

In many image and video processing applications such as video resolution enhancement [8], facial feature extraction [4] [23], image fusion [5] [18] and satellite image resolution enhancement [6] [9]. Resolution enhancement has always been a major issue to extract more information from them. One of the commonly used techniques for image resolution enhancement is Interpolation [8]. Interpolation in image processing is a method to increase the number of pixels in a digital image. There are three interpolation techniques, nearest neighbour, bilinear, and bicubic. Nearest Neighbour result in significant edge distortion. Bilinear Interpolation results in smoother edges but somewhat blurred appearance. Bicubic interpolation is more sophisticated than the other two techniques having fewer interpolation artifacts and produces smoother edges.

Saravanakumar J, Suganya P are with Dept. of EEE, K.S.R. College of Engineering, Tiruchengode. Email: ksrcekumar@gmail.com, rajsugan2005@yahoo.co.in

The 2-D wavelet decomposition of an image is performed by applying the 1-D discrete wavelet transform (DWT) along the rows, and then the along the columns. This generates four decomposed sub band images [3] low-low (LL), low-high (LH), high-low (HL), and high-high (HH). Wavelet based image processing gives low resolution for images with varying slopes. Wavelet Transform doesn't handle curves discontinuities well.

Curvelet transform [1] has been developed to overcome the limitations of wavelet. Though wavelet transform has been explored widely in various branches of image processing, it fails in representing objects having randomly oriented edges and curves as it is not good at representing line singularities. Curvelets uses only a small number of coefficients and handles curve discontinuities well. Curvelet Transform can be decomposed with four steps Subband Decomposition, Smooth Partitioning, Renormalization and Ridgelet Analysis [2]. By inversing the step sequence with mathematic revising, it is able to reconstruct the original image which is called Inverse Curvelet Transform. Fast Discrete Curvelet transform (FDCT) provides different frequency components for analysis and synthesis of digital image in multi-resolution analysis. The proposed technique has been compared with standard interpolation techniques. In this, an input image is transformed into frequency domain by applying 2D FFT. The product of image and curvelet in frequency domain is obtained and wrapped around the origin. Finally, the DCvT coefficients are generated by applying the inverse 2D FFT to the wrapped data.

II. INTERPOLATION TECHNIQUE

There are many methods available which are used for satellite image resolution enhancement. In this paper, Wavelet Zero Padding (WZP) [20] [21] and then interpolation techniques are used for comparison purposes. Interpolation is used to estimate the continuous function values from discrete samples [14] [15]. Interpolation includes many image processing applications such as image decompression, image magnification or reduction, sub-pixel image registration, image resolution enhancement [7] [11] [17] and to correct spatial distortions.

A. Bilinear Interpolation

Bilinear Interpolation determines the grey level value of the specified input coordinates from the average of four closest pixels and assigns that value to the output coordinates. Initially, two linear interpolations are performed in one direction (horizontally) and then another linear interpolation is performed in the perpendicular direction (vertically). The number of grid points needed to evaluate the interpolation function for one-dimensional Linear Interpolation, is two and for Bilinear Interpolation (linear interpolation in two dimensions), it is four. Bilinear Interpolation produces an image of smoother appearance than nearest neighbour interpolation, but the grey levels are altered in the process, results in blurred images.

B. Bicubic interpolation

Bicubic interpolation is sophisticated and produces smoother edges than bilinear interpolation. The computational time of bicubic interpolation is more. A new pixel is a bicubic function of 16 pixels in the nearest 4 x 4 neighborhood of the pixel in the original image The image is slightly sharper than that produced by Bilinear Interpolation, and it does not have the disordered appearance produced in Nearest Neighbour Interpolation. First, four one-dimension cubic convolutions are performed in one direction and then one more one-dimension cubic convolution is performed in the perpendicular direction. Thus to implement a two-dimension cubic convolution, a one-dimension cubic convolution is needed.

III. IMAGE RESOLUTION ENHANCEMENT USING TRANSFORMS

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Resolution is an important parameter in satellite image processing. Resolution enhancement is used to enlarge the input image in a way to make the output image looks sharper. Thus, increasing the resolution of an image affects the system performance. In image resolution enhancement by interpolation techniques, the main loss is in high frequency components (edges) which is due to the smoothing caused by interpolation. Thus, preserving the edges is necessary to increase the quality of an image. In this paper, DWT [11] [14] [16] is used to preserve the high-frequency components of the image.

DWT separates the image into different subband images. First by using horizontal filters to obtain L and H subbands, and then by using vertical filters LL, LH, HL, and HH. High frequency subbands contains the high frequency component of the image. Bicubic interpolation is applied to these four subband images. The low resolution image is obtained by low-pass filtering of the high resolution image as in [19], [20] and [21]. The low resolution image (LL subband) is used as the input for the proposed resolution enhancement process. The low frequency subband image contains less information than the original input image. Thus, the low resolution input image is interpolated with half of the interpolation factor.

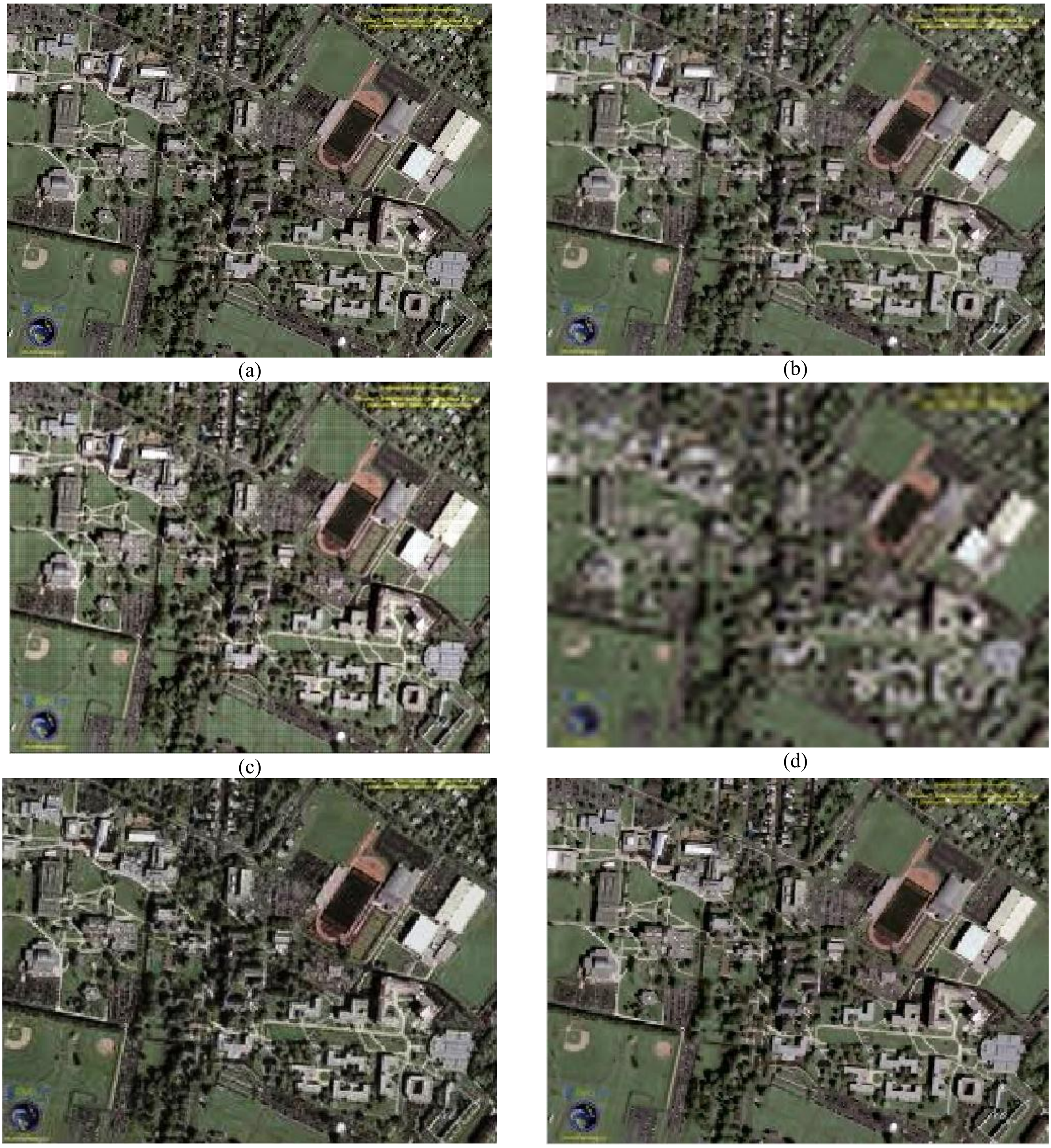
To obtain a sharper enhanced image [22], an intermediate stage is proposed in high frequency subband interpolation process. The low resolution input satellite image and the interpolated LL image with factor 2 are highly associated. The difference between the LL subband image and the low resolution input image are in their high frequency components. Hence, this difference image is used as an intermediate process to correct the estimated high frequency subbands. The estimation process is performed by interpolating high frequency subbands by factor 2 with the difference image (which is high-frequency components on low-resolution input image) into the estimated high-frequency images, then another interpolation with factor $\alpha/2$ is performed in order to reach the required size for IDWT process.

Similarly, LL subband image is used as input for the second level. The horizontal and vertical filters are used to obtain the LLLL subband image. The estimated high frequency subbands from the first level is used to obtain the sharper image by adding the difference image obtained between the LLLL subband image and the low resolution input image. The resultant image obtained is much sharper than the first level.

The curvelet approach of image enhancement is described as follow: First, apply the curvelet transform to the image. Then according to noise ratio of each subband, enforce sectional nonlinear enhancement to the coefficients. At last, apply the Inverse Curvelet Transform to the coefficients and come out the image with image enhancement on edge.

V. RESULTS AND DISCUSSIONS

The simulation tool used for processing satellite image is MATLAB and tested on different satellite benchmark images collected from satellite imaging corporation and GEOEYE. In order to show the superiority of the proposed method over the wavelet zero padding, interpolation techniques and DWT from visual point of view Figures. 1-2 are included. In those figures with low-resolution satellite images, the enhanced images by using bilinear interpolation, bicubic interpolation, enhanced images by using WZP, enhanced images using DWT and also the enhanced images obtained by the proposed are shown. Figure 1 is Kutztown University in Pennsylvania with resolution 258 X 195 taken by GeoEye-1 satellite. Fig 2 is Washington DC image with resolution 256 X 256.



(a) (b)

(c) (d)

(e) (f)

Figure 1 original image, (b) bilinear interpolation, (c) bicubic interpolation, (d) WZP output, (e) DWT, (f) DCvT.

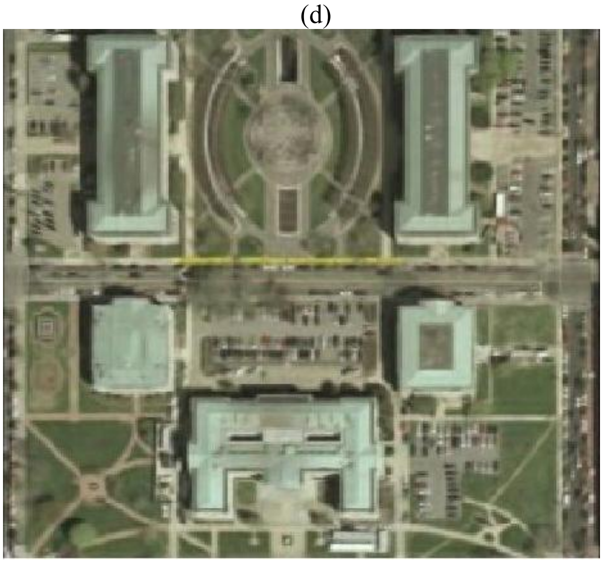
(a)

(b)

(c)

(d)

(e)



(f)

Figure 2 original image, (b) bilinear interpolation, (c) bicubic interpolation, (d) WZP output, (e) DWT, (f) DCvT.

From above figures, it is evident that the bilinear interpolation results in blurred appearance and bicubic interpolation produce an image slightly sharper than bilinear interpolation. In WZP discontinuities are artificially created at the borders. The Discrete Wavelet Transform based scheme generates artifacts due to a DWT shift-variant property. It is clear that the image, enhanced by using the proposed technique is sharper than the other techniques. Normally, the processed images are looking similar. However, when the image is enlarged, the losses in the image are obvious, and it will look blocky.

Visual comparisons as well as quantitative comparisons are confirming the superiority of the proposed method. Peak signal-to-noise ratio (PSNR) and Mean Square Error (MSE) are calculated to obtain quantitative results for comparison. PSNR can be obtained by using the following formula [12]

$$PSNR = 10\log_{10}\left(\frac{R^2}{MSE}\right)$$

where R is the maximum fluctuation in the input image. The higher the PSNR, the better the quality of the reconstructed image. An improvement in the PSNR magnitude will increase the visual appearance of the image.

The mean square error (MSE) is the MSE between original and reconstructed image defined as

$$MSE=\frac{1}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}(x(m,n)-y(m,n))^2$$

where x (m, n) and y(m, n) represent the original image and the reconstructed image respectively. The lower the value of MSE, the lower the error present in the image.

Table 1 Comparison of PSNR (dB) values

METHOD	PSNR (dB)	
	Fig 1	**Fig 2**
Bilinear	27. 4835	19.4766
Bicubic	31.1228	24.9384
WZP	28.1503	23.3906
DWT	33.5867	33.8008
Proposed Method	35.8503	35.3802

Table 1 is showing the comparison of PSNR (dB) between the proposed method with bilinear, bicubic interpolation, WZP and DWT. Improved PSNR values in Table 1 shows proposed method is improved in quality.

Table 2 is showing the Entropy values. In order to show the improvement obtained by the proposed satellite image resolution enhancement from information content point of view, the entropy of the images are calculated. As expected, highest level of information content is embedded in the original images. Compared to other techniques DCvT has higher quality of images.

Table 2 Entropy comparison

METHOD / IMAGE	ENTROPY	
	Fig 1	**Fig 2**
Low resolution satellite image (8-bit unsigned)	3.1165	5.6022
Original image	7.7368	7.3151
DWT Method	7.5607	6.4708
DCvT Method	7.6913	7.2942

Table 3 is showing the comparison of MSE and MAE between the proposed method using Daubechies (db.9) wavelet transform with bilinear and bicubic interpolation by means of MSE and MAE

Table 3 comparison of MSE and MAE

METHOD	MSE		MAE	
	Fig 1	**Fig 2**	**Fig 1**	**Fig 2**
Bilinear	0.5225	0.1068	0.718	0.1262
Bicubic	0.5014	0.0293	0.694	0.0662
DWT	0.0368	0.0197	0.412	0.0364
DCvT	0.0298	0.0034	0.376	0.0249

. The improved MSE and MAE value in Table 3 shows the proposed method has good quality images.

V.CONCLUSION

This paper discusses about improvement in the resolution of satellite images based on the discrete curvelet transform (DCvT). In this, an input image is transformed into frequency domain by applying 2D FFT. The product of image and curvelet in frequency domain is obtained and wrapped around the origin. Finally, the DCvT coefficients are generated by applying the inverse 2D FFT to the wrapped data. In DWT, an image is decomposed into different subband images. The input low-resolution image and high-frequency subband images are interpolated by bicubic interpolation. The input image is interpolated with half of the interpolation factor used for interpolation of the high-frequency subband images. Then, all these images are combined using IDWT to generate a more enhanced image. The quantitative metrics (PSNR, MSE, MAE and entropy) of the image calculated shows the superiority of this technique.

The results based on PSNR values show that the proposed method, in comparison with the interpolation techniques, and DWT show improvement in quality.

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Saravanakumar pursing Master of Engineering in Applied Electronics at K.S.R College of Engineering. He presented a paper in an International conference at Muthayammal Engineering College. His research interests include image processing.

Suganya has 13 years experience in teaching and research. She is currently doing her PhD. Her research interests include power systems.