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A Study on Various Satellite Image Resolution Enhancement Techniques

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Abstract- **Due to the low frequency nature and as the result of interpolation on satellite images, they may appear as blurred image. To enhance the frequency of those images, Resolution techniques are used. This is used in a several number of applications such as laser and inkjet printing, medical imaging, remote sensing, with some vital objections such as distortions, blurring aliasing, ringing artifacts etc. Enhancing the resolution of an image includes increasing the number of pixels presents to show the details of an image as well as sharpness of the image. This paper studied about the basics of interpolation with some conventional satellite image enhancement techniques and analyses the performance of various image resolution enhancement techniques for satellite images. These techniques are compared on the basis of Root mean square error (RMSE), Mean square error (MSE) and Peak signal to noise ratio (PSNR) factors.**

Keywords – **Discrete wavelet transform (DWT), Image resolution (IR), Image enhancement, Interpolation.**

I. INTRODUCTION

Satellite images are used in several applications such as astronomy, geographical information systems and geosciences studies. In the field of image processing the factor which is most important in satellite images is resolution enhancement. Fig.1 shows some satellite images which are taken from the Satellite imaging Corporation [1] .In Resolution Enhancement (RE) technique we vary the size of dots like pixels bit in image resolution it will increase more detail in the image. Enhancement is used for specific application to obtain more suitable image rather than original image. In image processing the processing of an input image performed and produces an output image which is superior to the input image. This includes Image Segmentation, Image Compression, Image Enhancement, Noise Removal, etc.

In this paper we have VI sections these include an introduction in section I which gives the brief knowledge of an image resolution, image enhancement and satellite image processing with some examples of satellite images. Then in section II we discussed about the basic types of interpolation and some basic techniques for satellite image enhancement. In section III we come to understand about the latest work and different combination of techniques for satellite image and resolution enhancement in detail. Then in section IV we compare those techniques which we studied in section III on the basis of the parameters defined in section IV. At the end in section V we conclude the above study by their qualitative and visual results by performing comparison with each other.

(a) *(b)*

Fig. 1 (a) Cartosat 1 adana Turkey (b) Palm Island of Dubai satellite images

II. INTERPOLATION AND BASIC IMAGE ENHANCEMENT TECHNIQUES

Interpolation is a technique in which conversion of a sampled digital signal to a higher sampling rate using various digital filtering techniques, some type of examples are nearest neighbor, bicubic and bilinear, whereas remapping of an image can used under wide variety such as changing perspective, correcting for lens distortion, and rotation of an image.

A Discrete Wavelet Transform is a wavelet transform in which wavelet coefficients are used. DWT is a technique which contains both frequency and time information of an image. On the other hand resolution is also one of the important feature which is used in various applications of interpolation are image enhancement, image resizing, image zooming, sub pixel image registration, image decomposition, image reduction, to correct spatial distortions and many more [17]. Fig. 2 showed the basic concept of enlarging the size of an image using interpolation. It is the process of transferring image from one resolution to another without losing image quality [14]. Figure below shows the effect of interpolation on an image.

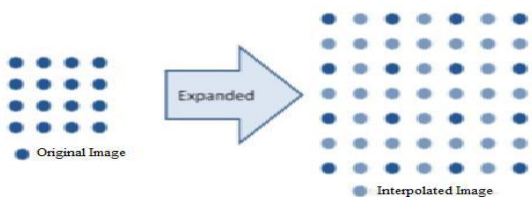

Fig.2: Effect of interpolation [14]

Interpolation techniques are to be divided into two categories:

1. Non-adaptive techniques
2. Adaptive techniques

Here we study only about the non - adaptive interpolation techniques.

Non-adaptive interpolation techniques are based on direct manipulation on pixels rather than considering any feature or content of an image. These techniques follow the same pattern on all pixels which is easy to perform and have less calculation cost. Various non-adaptive techniques are nearest neighbor, bilinear and bicubic.

A. Nearest Neighbour Interpolation*:* It is one of the most basic interpolation techniques which require less processing time among all other techniques. According to this technique the interpolated pixel is replaced by the nearest pixel. It is a simple method of linear interpolation and easy to implement. It gives good result when the image has high resolution pixels. By this some information at the edges are lost.

The interpolation kernel for nearest neighbor interpolation is [17]:

$$v(x) = \begin{cases} 0 & |x| > 0.5 \\ 1 & |x| < 0.5 \end{cases}$$

Where x = distance between interpolated point and grid point.

B. Bilinear Interpolation*:* It takes the weighted average of 4 neighborhood pixels to calculate its final interpolated pixel value. The result image obtained is much smoother than the original image. When all known pixel distances are equal, then the interpolated value is simply their sum divided by four [17]. This technique performs interpolation in directions, horizontal as well as vertical. This technique gives better result than nearest neighbor interpolation and take less computation time compare to bicubic interpolation. The interpolation kernel for bilinear interpolation is :

$$v(x) = \begin{cases} 0 & |x|>1 \\ 1 - |x| & |x|<1 \end{cases}$$

Where x = distance between interpolated point and grid point.

C. Bicubic Interpolation*:* It is best among all non-adaptive interpolation techniques. It takes a weighted average of the 16 pixels to calculate its final interpolated pixel value. These pixels are at various distances from the unknown pixel. Pixels those are closer given a higher weighting in the calculation [14]. It gives sharper images than previous two methods studied and gives better result but take more computational time. When time is not a constraint then this technique give the best result among all the non-adaptive interpolation techniques.

The interpolation kernel for bicubic interpolation is [3]:

$$v(x) = \begin{cases} 3/2|x|3 - 5/2|x|2 + 1 & 0<=|x| < 1 \\ -1/2|x|3 + 5/2|x|2 - 4|x| + 2 & 1<= |x|<2 \\ 0 & 2 < |x| \end{cases}$$

Where x = distance between interpolated point and grid point.

III. BASICS IMAGE ENHANCEMENT TECHNIQUES

A. Cycle Spinning [15] [16]: In this method, below steps are followed to get highly resolved image as shown in Fig.3:

- ❖ First we obtain an intermediate High Resolution (HR) image through WZP method.
- ❖ After that we obtain N number of images through spatial shifting, wavelet transforming and discarding high frequency component.
- ❖ Again, WZP process is applied to all Low Resolution (LR) images to obtain a number of High Resolution (HR) images.
- ❖ These High Resolution (HR) images are realigned and averaged to give a final High Resolution (HR) image.

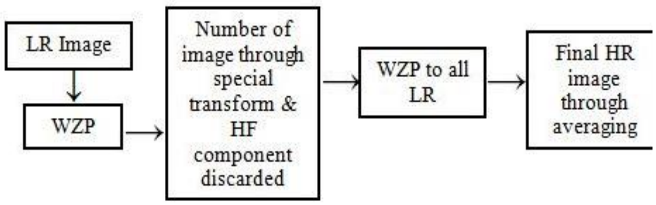

Fig 3.Cycle Spinning [15]

B. Undecimented Wavelet Transform (UWT) [8]: Undecimated wavelet transform is wavelet transform technique which does not use decimation after the decomposition of images into different frequency sub bands. In this method, first WZP method is applied to obtain an estimate of HR image. If the LR image is denoted with Y of size m*n then the estimated HR image is given by:

$$X = \text{IDWT}\begin{pmatrix} Y & a \\ a & a \end{pmatrix}$$

Where, a is the zero matrix of size m*n and IDWT is the inverse discrete wavelet transform. In next step, undecimated wavelet transform is implemented on the estimated HR image, as a result of which image is decomposed into two bands called estimated details and approximation coefficients. Then these approximation coefficients are replaced by initially estimated HR image and inverse UWT is taken to obtain the final HR image refer to Fig.4.

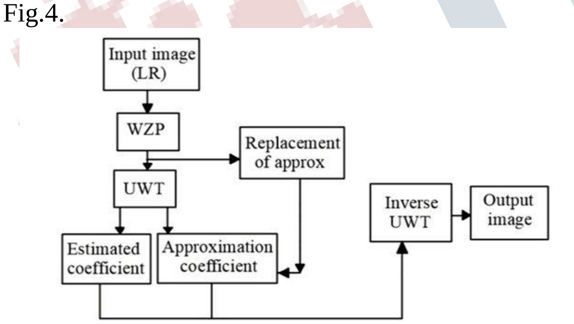

Fig 4: UWT Method [8]

C. Wavelet Zero Padding (WZP) [2]: Wavelet zero padding is one of the simplest methods for image resolution enhancement shown in Fig.5.In this method, wavelet transform of Low Resolution (LR) image is taken and zero matrices are embedded into the transformed image by discarding high frequency sub bands through the inverse wavelet transform and thus High Resolution (HR) image is obtained.

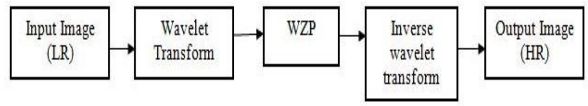

Fig 5: WZP Method [2]

IV. IMAGE RESOLUTION TECHNIQUES

A. Vector-Valued Image Regularization with Partial Differential Equations (VVIR-PDE)

In order to control the local smoothing behavior of image, this technique is used. The vector edges which have high vector variants to preserve the image information while removing the noise. So, the VVIR-PDE technique is used for image denoising. This VVIR-PDE technique mainly uses anisotropic smoothing to preserve the global features of vector images. This technique follows desired local geometric properties [4]. It is used in wide range of applications such as color image restoration to remove the noise, color image inpainting to remove the text in an image, color image magnification to remove bloc effects of an image, etc shown in Fig.6.

Fig.6: By Using vector-valued regularization PDE's for inpainting, magnification and noise removal of an image [4].

B. Inter Sub band Correlation Technique (ISC)

This method [6] which uses same phase for the sub bands. So, the sampling phase is considered. The method has the filter bank to estimate the sub bands. The sub bands have correlation that is between low frequency band and high frequency band. If we have different phases, the sub bands will have low correlation with one another. This method has three steps.

1) First apply the wavelet transform to all different phases of each sub band.
2) The filters are used to estimate the bands in higher level.

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3) Inverse wavelet transform is applied to enhance the resolution of an input image.
Thus, using the same phase for estimating the sub bands, this method will produce a time consuming process.

C. Singular Value Decomposition (SVD) Transform

This transform is used to enhance the satellite images and it is used to improve the brightness of an image. Using DWT technique the image is divided into sub bands. The LL sub bands are obtained from the input image [7]. And the singular value matrix is estimated for the Low-Low sub band image. Then the inverse DWT technique is applied to enhance the brightness of an image. The SVD transform gives the better brightness when combined with DWT [7], which can be shown Fig.7 with the histograms of the original image and the low contrast images compared with the histograms of the attained images from SVE and the histograms of the attained images from GHE.

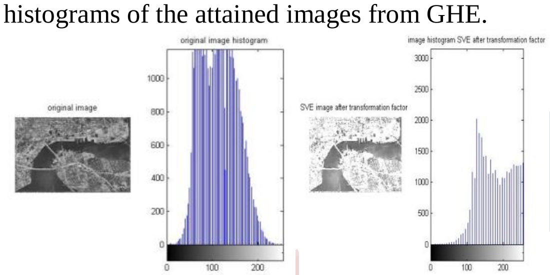
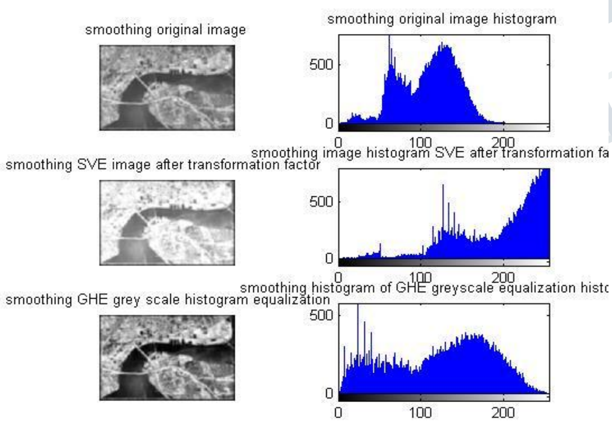


Fig.7: (a) Original image in Fig1 and SVE image in Fig2 with their histograms.



(b) Original, SVE and GHE image after smoothing filter with their histogram

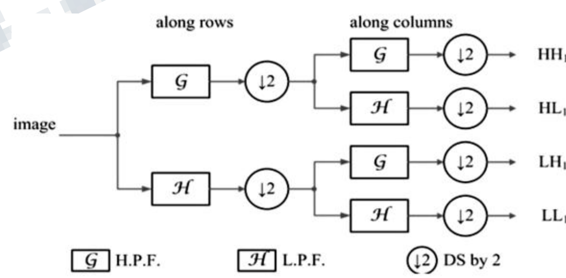
Fig 8: (a) and (b) shows the Results after Simulation of satellite image equalization by SVD

D. Stationary Wavelet Transform (SWT)

The Stationary Wavelet Transform is used to overcome the lack of translation-variance of the Discrete Wavelet Transform (DWT). And SWT technique is redundant. As like DWT, the SWT also divides the input image into different sub bands. The high frequency sub bands obtained by DWT and SWT are added with each other which mean they have the same size. That is, the interpolated high frequency sub band coefficients have been corrected by the SWT high frequency sub band coefficients [3]. After that, the images are combined using inverse process to get resolution enhanced image. So, the technique generates a super resolved image.

E. Discrete Wavelet Transform (DWT)

The satellite images have high frequency contents as well as low frequency contents. And the image may have losing of high frequency contents. So, the DWT technique has been employed for resolution to preserve the high frequency components of the satellite images [10]. The process is to divide the satellite input image into four sub bands. They are Low-Low(LL), Low-High(LH), High-Low(HL), High-High(HH) shown in Fig.6 along with its block diagram. Then the high frequency sub bands are estimated. The high frequency sub band images and the low resolution input images are interpolated and using inverse DWT we can get a resolution enhanced image [2]. The interpolation process is used to preserve high frequency contents of the image. The DWT technique is mainly used to produce the sharper enhanced image.



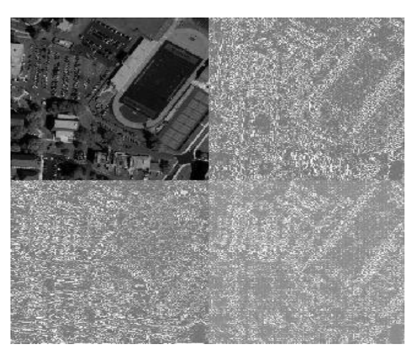


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Fig.9: Block diagram and LL, LH, HL, and HH subbands of an image obtained by DWT [2]

F. Adjacent Pixel Algorithm (APA)

This algorithm is used to produce sharper and clear images. The process which considers the pixel values for resolution. It is the method to increase the number of pixels in satellite images. So, the input image is divided into sub bands. Then, the pixel values are calculated. The Low-Low (LL) sub band which have low pixel values. An extra column is added to LL sub band and we have to assign the average pixel value of the neighboring pixels [5] shown in Fig 10. So, the pixel values are increased in LL sub bands. Then, the image gets clearer. As the pixel value increases, the images will get sharper and clearer.

Algorithm AP

INPUT: Discrete Wavelet Transformed Image
OUTPUT: Interpolated image
Begin
1. Take LL sub-band
2. Add a new empty column
3. Assign pixel value by computing average of nearest Neighboring pixels.
4. Goto step 2
5. Repeat for all sub-bands
End

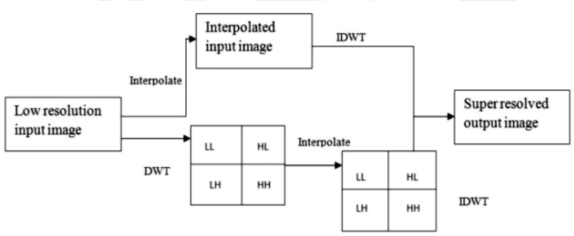

Fig.10 Block Diagram of algorithm by APA [5]

G. Dual-Tree Complex Wavelet Transform (DT-CWT)

In order to reduce the artifacts, the DT-CWT technique is used for satellite images [12]. It is also used in terms of reduction of aliasing that is distortion to the image, ringing that is unwanted oscillation of a signal presented in an image. The frequency of an image may not be continuous due to shift variant property. So, the property keeps on changing. The DT-CWT technique [9] is used to overcome the shift variant property. That is, Shift invariant and also directionally selective. The process includes,

1) Divide the Low Resolution (LR) input image into different sub bands.

2) The sub bands separated into coefficient and wavelet coefficient sub bands.

3) The wavelet coefficient sub bands and low resolution input image are interpolated.

4) Then, the high frequency sub bands are passed through filters to reduce the noise.

5) The filtered high frequency sub bands and low resolution image are combined using inverse DT-CWT to produce a high resolution image. Shown in Fig 11.

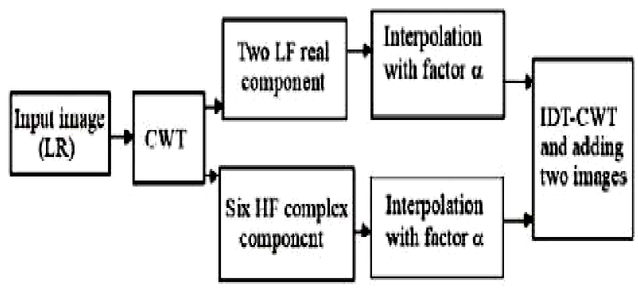

Fig.11: DT-CWT Method [12]

V. PERFORMANCE ANALYSIS

Tables 1 and image results of Fig 12 below shows the Comparison of Lena image using different interpolation Techniques according to their PSNR values which stated in section II of this paper. [14] Similarly, Table 2 and image results in Fig 13 shows the comparison of above three image enhancement techniques [13], which are mentioned in section II of this paper.

(a) (b)

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(c) (d)

Fig.12: (a) Original image (b) Nearest neighbor image (c) Bilinear image (d) Bicubic image

TABLE 1 COMPARISON OF ABOVE THREE INTERPOLATION TECHNIQUES [14]

Interpolation Techniques	PSNR(db)
Nearest neighbour	26.05
Bilinear	27.12
Bicubic	27.18

(a) (b) (c)

Resolution Techniques	Advantages / Disadvantages
APA	Gives clear view of an image / Loses linear features
ISC	Less computational complexity / Sometimes have low correlation
SVD	Improves the brightness of image / Cannot give clear image

(d)

Fig. 13:(a) Original LR image (b) Image by WZP (c) Image by CS (d) Image by UMT

TABLE 2. SHOWS THE COMPARISON OF ABOVE THREE IMAGE ENHANCEMENT TECHNIQUES [13]

Methods/Images	MSE	RMSE	PSNR(db)
WZP	0.0467	0.2161	32.2722
CS	0.0706	0.2658	27.4267
UWT	0.0675	0.2597	28.6002

Table 3 Shows the Comparison of resolution enhancement of the all above mentioned techniques in section III is done by using MATLAB software according to PSNR and RMSE qualitative analysis of typical available values. All these values are taken as the typical available value from their respective proposed papers.

TABLE 3. SHOWS THE COMPARISON OF RESOLUTION ENHANCEMENT ABOVE MENTIONED TECHNIQUES BY (PSNR AND RMSE) QUALITATIVE ANALYSIS OF TYPICAL AVAILABLE VALUES AND THEIR ADVANTAGES AND DISADVANTAGES.

Resolution Techniques	Typical Available values of Mean Square Error (MSE)	Typical Available values of Peak Signal To Noise Ratio (PSNR)
DWT [10]	0.0419	13.7804
SWT [10]	0.0464	13.3332
VVIR-PDE [10]	0.0268	15..6780
DT-CWT[10]	0.0243	16.1566

VI. CONCLUSION

This paper analyses the performance of various resolution techniques. Whereas resolution enhancement techniques, which are not based on wavelet transforms have the drawback of losing high-frequency components, which results in blurring. These transforms and techniques are implemented using MATLAB tool and combined in this paper so that the better performed technique among all can be evacuated which is shown in Table 4. The DT-CWT yields better performance, after the interpolation of wavelet coefficients. In Future, Multi Wavelet Transform can be used which produce fewer artifacts when compared to other techniques for hyper spectral satellite images and it also enhances the performance of an satellite image in terms of MSE and PSNR.

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