SATELLITE IMAGE RESOLUTION ENHANCEMENT USING DISCRETE WAVELET TRANSFORM

A DISSERTATION

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CANDIDATE'S DECLARATION

I hereby declare that the dissertation entitled **"Satellite Image Resolution Enhancement using Discrete Wavelet Transform"** submitted by Shalini Sharma for the degree of Master of Technology in Electronics and Communication Engineering is carried out by me under the guidance and supervision of **Dr. Sudipta Majumdar** at Delhi Technological University, Delhi during the period from January, 2018 to Sept, 2018.

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CERTIFICATE

I hereby certify that the Project Dissertation titled **"Satellite Image Resolution Enhancement using Discrete Wavelet Transform"** which is submitted by Shalini Sharma**, (2K16/SPD/16) Electronics and Communication, Delhi Technological University, Delhi** in partial fulfillment of the requirement for the award of the degree of Master of Technology is a record of the project work carried out by the student under my supervision and guidance.

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ABSTRACT

Enhancement of image resolution is an important area as these images gives a lot of information about climatic changes, disaster prediction i.e tsunami and cyclone detection, traffic monitoring etc.

The thesis report focuses on enhancing the image resolution using Discrete wavelet transform and then performing the Lanczos interpolation of high frequency components to enhance the resolution. Lanczos interpolation has been used as it gives better results as compared to other conventional interpolation techniques.

The parameter analysis of high resolution image has been carried out in which PSNR, MAE, MSE and Pearson correlation coefficient has been calculated.

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Finally, I dedicate my project report to my parents for their love, support and encouragement without which this would not have been possible.

SHALINI SHARMA

CONTENTS

List of Figures

List of Abbreviations

DWT	Discrete Wavelet Transform
LWT	Lifting Wavelet Transform
LR	Low Resolution
RE	Resolution Enhancement
HR	High Resolution
NLM	Non Local Means
PCA	Principle Component Analysis
SWT	Stationary wavelet transform
APA	Adjacent Pixel Algorithm
WZP	Wavelet Zero Padding
CS	Cycle Spinning
PSNR	Peak signal to noise ratio
MAE	Mean absolute error
MSE	Mean Square error

CHAPTER ONE
INTRODUCTION

The term "Satellite imagery" means those digital images which have been acquired by those artificial satellites which are moving on the orbit around the Earth. In 1960,the first Satellite imaging system was launched by United States to spy on the Soviet Union. Apart from military applications, satellite imagery has also been used for mapping purpose, prediction of weather, environmental monitoring, medical science, and archaeological surveys. These images are mostly required by government, large corporations and educational institutions.

In today's era, there is an increase in the demand for better quality satellite images in wide applications like in medical science, astronomy, object recognition and object detection. Satellite images are now required for diverse fields so as to monitor the processes of surface of Earth, changes of atmosphere, estimating the geographical, biological and physical parameters etc.

Various image resolution enhancement techniques have been discussed later in this chapter. Some of the advantages of the Satellite Image Resolution are tracking of weather systems for the prediction of occurrence of storms like hurricanes, cyclones, tsunami with great accuracy and precision.

The thesis report focuses on enhancing the image resolution using discrete wavelet transform and then performing the Lanczos interpolation of high frequency components to enhance the resolution.We have done this (reference [1]) and calculated the highr esolution enhanced image parameters like PSNR (Peak signal to noise ratio, MSE (Mean square error) and Pearson correlation coefficient.

1.1 Literature Review

Various methods have been used in literature for image resolution enhancement

1. Yong Yang, Shuying Huang et. al. [2] proposed method for fusion of two or more images. Each object in the image is placed at a different distance and camerafocuses each object one by one and combine them. The paper showed the importance of wavelet coeficients, fusion technique using wavelet. Input images are decomposed by DWT method. After this, fusion rules are applied to fuse the low frequency coeficients with high frequency coeficients of image. Daubechies db8 is generally used as wavelet basis. This method can achieve better visual quality and comparatively better objective evaluation index. But the limitation of this method is that it is not suitable for pictures obtained from multiple sources such as the pictures obtained in the field of remote sensing and medical etc.

2. S Pavithra and Dr. Bhargvi [3] introduced the method for fusion of multi resolution two dimensional remote sensing images using wavelet approach by using the combined gradient approach. It decomposes registered image into its sub images by forward wavelet transform technique which uses different resolutions. Image fusion is used depending upon the high frequency sub images and final image is reconstructed back by using inverse wavelet transform. This reconstructed image is more informative as it has gathered information from all other different image sources. The main advantage is that the proposed algorithm is independent of domain. It can be used with multi-modal images and it also preserves the edge information present in an image. Limitation of this method is that it needs more space and it is computationally more expensive as compared to others.

3. P. Suganya, N. Mohanapriya et. al. [5] proposed DWT and SWT for effective image decomposition. A discrete wavelet approach uses discrete wavelet coeficients. The DWT technique captures both types of information, frequency and location details of an image. The images obtained from the satellites consists of both high frequency and low frequency components.

The DWT approach has been used for resolution to preserve the high frequency components of the satellite images. Input image is divided into four frequency sub bands. They are low-low (LL), low-high (LH) , high-low (HL), high-high (HH) subbands. High frequency subbands images interpolated with low resolution input image and then a resolution enhanced image is obtained through inverse DWT. Generally, interpolation process is used to enhance the resolution of the image and it also preserves the information. Interpolation process is used to enhance resolution. Sharper and enhanced resolution images are produced by using DWT technique.

4. Arya P Unni [6] author proposed method for enhancement of satellite color images. If we use the concepts of 2D discrete wavelet transform, threshold decomposition and morphological filtering, it can easily distinguish unnecessary noise contents of the image and high frequency components of the image. Haar filter can also be used to filter out the unnecessary frequency components from the image. In the paper , Histogram Equalization technique was used for enhancement of resolution of satellite images by normalizing image intensities. The problem with this method is that it is not able to maintain an average brightness level due to large differences in intensity values of pixels. Brightness level is either under or over saturated but is not maintained at a level in the processed image. The limitation of this technique is that it cannot be used for large images. Satellite images are large images so this method is not useful in that case.
5. Wenkao Yang, Jing Wang et. al.[9] proposed method based on principal components analysis (PCA). It is statistical approach that can convert multivariate data with correlated variables to uncorrelated variables. The new variables can easily be obtained as linear combination of existing variables. The technique has to be utilized for many applications like image encoding and decoding, image fusion applications, image data compression and dilation, image enhancement algorithms. During the process of image fusion, PCA method will produce uncorrelated images. Mostly, the principle component obtained is replaced by panchromatic band, which is having higher spatial resolution. Finally, inverse transform is performed to get the image in RGB colour . Limitation of this method is that PCA based image fusion method gives weak details about colour.

6. Anumolu Lasmika, K. Raveendra [7] proposed a method for improving quality of satellite images. Author presented a method based on discrete

wavelet transform for decomposition and applied threshold method on it. The areas of the edges were identified by using threshold decomposition method. After this, morphological filters are used for sharpening of images.This method works for sharpening and reducing the distortion of an image.

7. Deepika G. Firake1, Dr. P. M. Mahajan et. al. [10] performed Image resolution enhancement followed by non local means denoising technique. Non Local Means denoising will perform the weighted average of pixels in a particular region. It will compute the weighting function and then the similar pixels will be assigned more weights. This is more accurate than local means averaging.

8. Ravi B. Mehta et. al. [11], presented work in survey paper. The survey paper gives an idea of the performance of different resolution enhancement techniques.

1.2 Image Resolution Enhancement

Image resolution enhancement is required for tracking of weather systems, for the prediction of occurrence of storms like hurricanes, cyclones, tsunami with great accuracy and precision. It is also beneficial to determine the area under forest cover, area under water and to analyse certain issues regarding global climate change like Global warming etc. Large areas can be covered using satellite cameras and due to the digital nature of information, it can be easily integrated with software.

Some of the resolution enhancement techniques are:

1. Wavelet Zero Padding
2. Cycle spinning
3. Undecimated Wavelet Transform
4. Interpolation

The thesis is organised as follows :

- The Chapter two presents brief theory of image resolution enhancement techniques.
- The Third Chapter presents a brief discussion on wavelet transform. Complex Wavelet Transform and Discrete Wavelet Transform has been presented.
- The work of the thesis is presented in chapter four.
- Chapter five presents simulation results.
- Future work scope is presented in chapter six.

CHAPTER TWO

IMAGE RESOLUTION ENHANCEMENT TECHNIQUES

2.1 Wavelet Zero Padding:

It is a very simple method which can be used for image resolution enhancement. In this method, an assumption is made that the signal is zero outside its original support. Zero padding is done by appending a string of samples of zero value at the end in time domain sequence. In spectral analysis, zeros addition is performed to improve the accuracy of the reported amplitudes. If zero-padding is not performed, the output will contain attenuated input frequencies.

Zeros addition in the time domain corresponds to optimal interpolation in other domains,which will restore amplitude. Wavelet transform is defined only for signals having infinite length so finite length signals need to be extended before their transformation.

One of the common method used for extension is zero padding. The technique modifies the intersample spacing in spectral domain which represents result.

Drawbacks of zero padding:

1. At the border, the discontinuities are artificially created.
2. The shift changes the array positions which are relative to the frequency of interest which will cause the attenuation.

2.2 Cycle Spinning

The decimated wavelet transform is shift-variant which is not desirable and therefore, distorted wavelet coefficients are obtained in the output. Due to quantisation of coefficients during compression applications or non-exact estimation of high frequency coefficients in resolution enhancement applications, cyclostationarity is introduced in the image which generates ringing effect in the neighborhood region of discontinuities. This technique has been proved to be effective against ringing effect.

To obtain highly resolved image, the steps are:

- Wavelet zero padding(WZP) method is used to obtain an intermediate image having high resolution.By using wavelet transforming , multiple images have been obtained through shifting and ignoring high frequency components.

- High resolution image is obtained by applying WZP process to all low resolution (LR) images.A High Resolution (HR) image is produced by averaging all high resolution (HR) images.

2.3 Undecimated Wavelet Transform (UWT)

In undecimated wavelet transform technique, decimation or downsampling is not performed after decomposing. An estimate of HR image is obtained by applying WZP method. In next step, this technique is implemented on the estimated high resolution image, due to which image is decomposed into two types of coefficients approximation coefficients and estimated detailed coefficients.

2.4 Interpolation

By using interpolation, we can increase the total number of pixels in a given per unit area. This process is followed by upsampling. This will increase the total pixel count of the given image. Only high frequency components are interpolated as they contain the sharp intensity variation information.

Some of the commonly used interpolation techniques used are:

1. Nearest neighbour interpolation
2. Bilinear interpolation
3. Bicubic interpolation
4. B Spline interpolation

2.4.1 Nearest Neighbour Interpolation:

It is very basic method for interpolation. The value of the nearest sample is assigned to each output pixel. The kernel function is given by:

$$h(x) = \begin{cases} 0 & \text{for } |x| > 0 \\ 1 & \text{for } |x| < 0 \end{cases} \quad (1)$$

The Fourier transform of this kernel function will be a sinc function as shown:

$$H(\omega)=\text{sinc}(\omega/2) \quad (2)$$

The image quality obtained by this method is not so much good due to the nature of kernel function in frequency domain . The Fourier transform of a constant function in time domain gives a sinc function in frequency domain. The limitation is that its gain falls off quickly in the passband.

2.4.2 Bilinear interpolation

The output coordinates will be assigned with a value which is weighted average of the nearest four pixels of the input coordinates.

So, in this way values of random positions will be known. Linear interpolation is performed in different directions.

Linear interpolation is performed in x direction and y direction. The resultant equation obtained as whole is quadratic in nature because it is obtained by combining two linear interpolation equations of

The interpolation kernel is given as

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

X is distance between two points to be interpolated

2.4.3 Bicubic interpolation

The bicubic interpolation has some advantages over cubic interpolation in two dimensional regular grid. The interpolated surface obtained by bicubic interpolation is much smoother than those obtained by any other interpolation technique. It makes use of polynomial algorithm, cubic algorithm or cubic convolution algorithm. Sixteen nearest pixels related to the input coordinates are taken and their average is calculated. This value is used to determine the grey level value of the image. This calculated value is then assigned to the output coordinates. Bicubic interpolation stands for cubic convolution interpolation in two dimension. Sixteen grid points will be required to evaluate the interpolation function.Two grid points are required for horizontal and perpendicular direction. The interpolation kernel is:

$$w(x) = \begin{cases} (a+2)|x|^3-(a+3)|x|^2+1 & for\ |x| \le 1 \\ a|x|^3-5a|x|^2+8a|x|-4a & for\ 1<|x|<2 \\ 0 & otherwise \end{cases}$$

where x represents one dimension of the kernel and w(x) shows the amplitude of kernel at that point and a varies from -0.5 to -0.75. The scientist named as 'keys' proposed that by setting a=-0.5 ,w(x) will converge.

The limitation of this method is that when the image is convolved with kernel w(x), the discontinuities are present due to piecewise nature of kernel. This will not give smooth images.

2.4.4 Basic-splines (B-spline) :

To overcome the shortcomings of previous interpolation techniques, B-Splineis used. It smoothly connects the polynomials with pieces.

The Box filter, denoted as Bsp_0 is convoluted n times to obtain B-Spline equation having degree n .To represent B-spline of degree 1, two box filters Bsp_0 are convolved. To obtain a second degree B-spline Bsp_2 equation, Bsp_1

is convolved with Bsp_0 i.e Bsp_0*Bsp_1

$Bsp_1=Bsp_0*Bsp_0$

$Bsp_2=Bsp_0*Bsp_1$

$Bsp_3= Bsp_0*Bsp_2$

The interpolation kernel h(x) is given by:

$$h(x)= 1/6\begin{cases} 3|x|^3 - 6|x|^2 + 4 & 0 < |x| < 1 \\ -|x|^3 + 6|x|^2 - 12|x| + 8 & 1 \leq |x| < 1 \\ 0 & 2 \leq |x| \end{cases}$$

where x is the independent variable which helps in constructing the kernel function h(x)

CHAPTER THREE

WAVELET TRANSFORM

In signal processing, wavelets are generally used to analyze multiresolution images. Wavelets are generally used for two purposes for noise removal and for image compression.

3.1 Continuous wavelet Transform

Let us definea function ψ(x) and assume that it is band limited with its d.c component equal to zero.Translated and scaled version of function ψ(x) is defined as:

Continuous wavelet transform of f(x) is defined as:

$$\psi_{s,\tau}(x) = \frac{1}{\sqrt{s}}\psi\left(\frac{x-\tau}{s}\right)$$

Where

τ : translation parameter
s : scaling parameter

$$W_{\varphi}(s,\tau) = \int_{-\infty}^{\infty} f(x)\psi_{s,\tau}(x)\,dx$$

in which a continuous function in one variable has been transformed into a continuousfunction in two variables. Each section of the signal f(x) is compared with the wavelet function and the correlation between the two iscomputed.

Inverse continuous wavelet transform is given by:

$$f(x) = \frac{1}{C_{\psi}}\int_{0}^{\infty}\int_{-\infty}^{\infty} W_{\psi}(s,\tau)\frac{\psi_{s,\tau}(x)}{s^2}\,d\tau\,ds$$

where

$$C_\psi = \int_{-\infty}^{\infty} \frac{|\Psi(\mu)|}{|\mu|} d\mu$$

where $\Psi(\mu)$ is the fourier transform of $\psi(x)$

3.2 Discrete Wavelet transform

It is same as continuous wavelet transform except that the scales are choosen based on the powers of 2. There is no need to calculate wavelet coefficients at each possible scale.

$$\psi_{j,k}(x) = 2^{j/2}\psi(2^j x - k)$$

The discrete function f(n) can be represented as the weighted sum of wavelet function and approximation coefficients as shown below

$$f(n) = \frac{1}{\sqrt{M}}\sum_k W_\varphi(j_0,k)\varphi_{j_0,k}(n) + \frac{1}{\sqrt{M}}\sum_{j=j_0}^{\infty}\sum_k W_\psi(j,k)\psi_{j,k}(n)$$

where j_0 is the scale and n= 0,1,2…….M

“Approximation” coefficients

$$W_\Phi(j_0,k) = \frac{1}{\sqrt{M}}\sum_x f(x)\,\varphi_{j_0,k}(x)$$

“Detail” coefficients

$$W_{\Psi}(j,k) = \frac{1}{\sqrt{M}} \sum_{x} f(x)\, \psi_{j,k}(x)$$

Two sets of coefficients are computed: approximation coefficients CA_1, and detail coefficients CD_1. The signal is convolved with a low pass filter to get approximation coefficients and convolved with the high pass filter to get detailed coefficients. This process is further followed by dyadic decimation.

Limitations of DWT

3.2.1 Lack of Shift Invariance

The limitation is due to the lack of shift covariance , but the term shift invarient has been used till now. If the output is not dependent on the location of the data in the input, then the process is said to be shift invariant.

If the total energy of the subband image is not affected by shift applied to the input, the transform will be considered as shift invariant.

After each filtering stage, down sampling is performed due to which aliasing occurs which results in shift variance.

If downsampling stage is not performed, this problem can be solved but it will introduce large amount of redundancy and complexity will be increased.

Figure 3.3 shows the shift variance of DWT. The input shown in the figure is a one dimensional step response signal. Four level decomposition has been performed and each subband signal has been shown.

At the bottom, level four scaling function has been shown in the figure. The variation of energy in each subband signal shows the shift variance or shift dependency. In image processing applications, the shift dependence of the DWT has limited its suitability for texture analysis. This is because in any given image, texture may present itself under any shift.

If texture details have to be known by its sub band decomposition, then it will be constant and does not depend on the location. The transform used to analyse texture should be shift invariant.

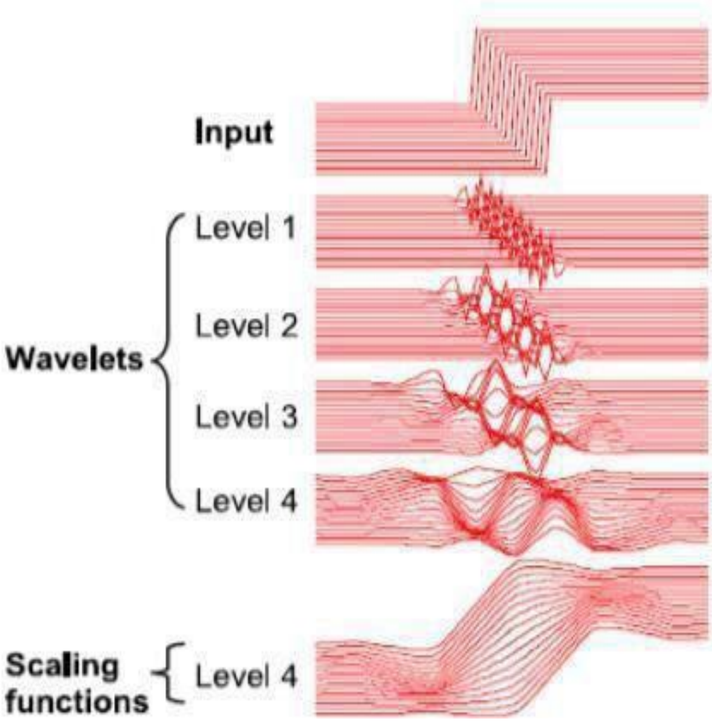

Figure 3.1 Shift Variance in DWT

3.2.2 Weak Directional Selectivity

After the application of filtering operation, four subimages will be obtained using real filters. Each subband image contains both positive as well as negative components of frequency. Real filters cannot distinguish between positive and negative frequency components which introduces weak directional selectivity of the DWT. It is also one of the reason which makes DWT not suitable for texture analysis. The magnitude of each wavelet coefficient is shown by the intensity value of each subband**.**

CHAPTER FOUR

PROPOSED METHOD

4.1 Block Diagram

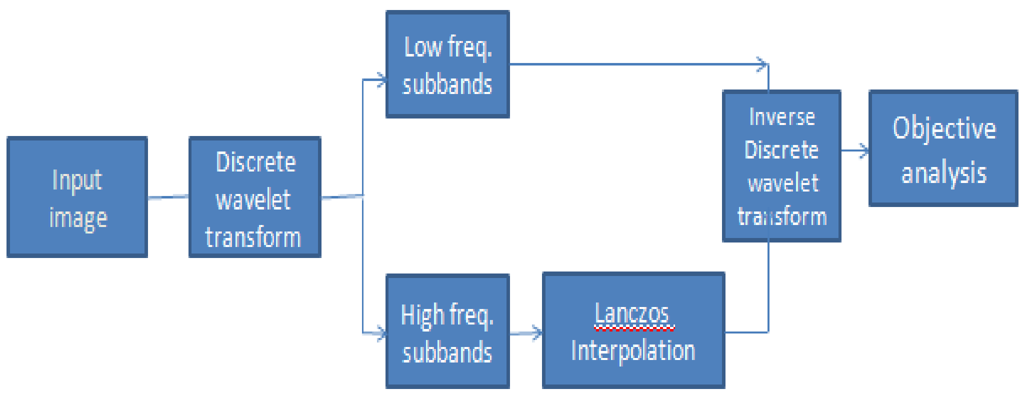

Fig: 4.1 Block Diagram

At first, DWT is performed to obtain different frequency components. After this, high frequency subbands or bandpass coefficients have been interpolated with the help of Lanczos filtering. Lanczos filtering has many advantages over other interpolation techniques. After this, inverse discrete wavelet transform is applied.

Finally, image resolution enhancement has been performed using different parameters. By doing all this, an enhanced version of the image is obtained. The resulting output image will have sharper edges as compared to the image which would be obtained by applying direct interpolation techniques.

4.2 Lanczos interpolation:

It performs upsampling and append the samples of the digital signal among different sample points. Mapping of every single sample point of the input signal is performed with the lanczos kernel. A normailzed function which is in the form of sinc is multiplied with another sinc window known as Lanczos window such that (sinc(x/b))for $-b \leq x \leq b$ is called as Lanczos Kernel.

The Lanczos kernel is given by L(x)

$$L(x) = \begin{cases} \text{sinc}(x)\text{sinc}(x/b) & \text{if} \quad -b<x<b \\ 0 & \text{otherwise} \end{cases}$$

where b is an integer and the size of the kernel will be determined by it . The Lanczos kernel has b-1 lobes in the positive side and b-1 lobes in the negative side, and one lobe in the centre .Thus a total of 2b − 1 lobes are present. If the signal has S_i number of samples the interpolated value S(x) is obtained by the discrete convolution of those samples with the Lanczos kernel.

$$S(x) = \sum_{(i=[x]-b+1)}^{([x]+b)} S_i L(x-i)$$

where b is the size of the filter

[x] is known as floor function of x i.e it evaluates to nearest integer less than or equal to x.

4.3 Algorithm of Lanczos interpolation:

Step 1: Specify sampling frequency and sampling interval

Step 2: Specify the size of kernel

Step 3: Repeat the above step for x direction and y direction seperately

Step 4: Creation of kernel by multiplying sinc(x) with sinc(x/a)

Step 5: Denote rows of kernel by kx and denote columns of kernel by ky

Step 6: Kernel matrix is assigned as kx.ky'

Step 7: Perform convolution of input image with the Lanczos kernel

4.4 Image resolution enhancement calculations

1. **Mean square error calculation**

   MSE = sum((enhanced image - original image).^2)/length(original image);

2. **Root Mean Square Error Calculation**

   RMSE = sqrt(MSE);

3. **Peak Signal to Noise Ratio calculation**

   PSNR_VALUE = 10*$\log_{10}$(max(enhanced image))/(MSE);

   Or

   PSNR_VALUE = 20*$\log_{10}$(max(enhanced image)/(RMSE);

   The value of PSNR_VALUE comes in decibels(db). MSE and RMSE have been described in 1 and 2.

4. **Pearson Correlation Coefficient(r)**

   It tells about the similarity index between two signals enhanced signal and original signal. It's value lies between plus one and minus one, where 1 is total positive linear correlation, 0 is for zero correlation and minus one is total negative linear correlation.

   r = cov(enhanced image,original image)/std(enhanced image).*std(original image)

   where,

   cov(enhanced ,original)=E[(enhanced-mean(enhanced).*(original-mean(original)]

   std = standard deviation

   std(enhanced image)= enhanced image - mean(enhanced image)

   std(original image) = original image - mean(original image)

CHAPTER FIVE

SIMULATIONS AND RESULTS

5.1 Output

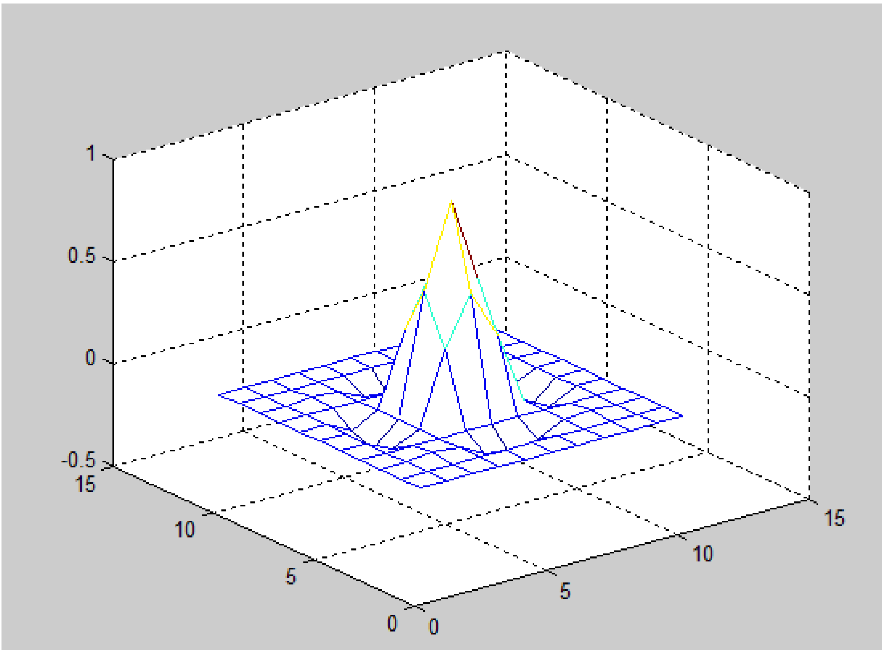

Fig 5.1 Lanczos Kernel

Fig 5.1 shows the three dimensional representation of Lanczos kernel function which has been obtained by multiplying a sinc function with sinc window.The size of the window has to be specified. The signal which has to be interpolated is convolved with this kernel to obtain the interpolated signal.

Lanczos interpolation has been employed in this thesis, the advantage of Lanczos interpolation over other interpolation methods is that the gain does not falls off quickly instead it depends on the specification of the kernel.

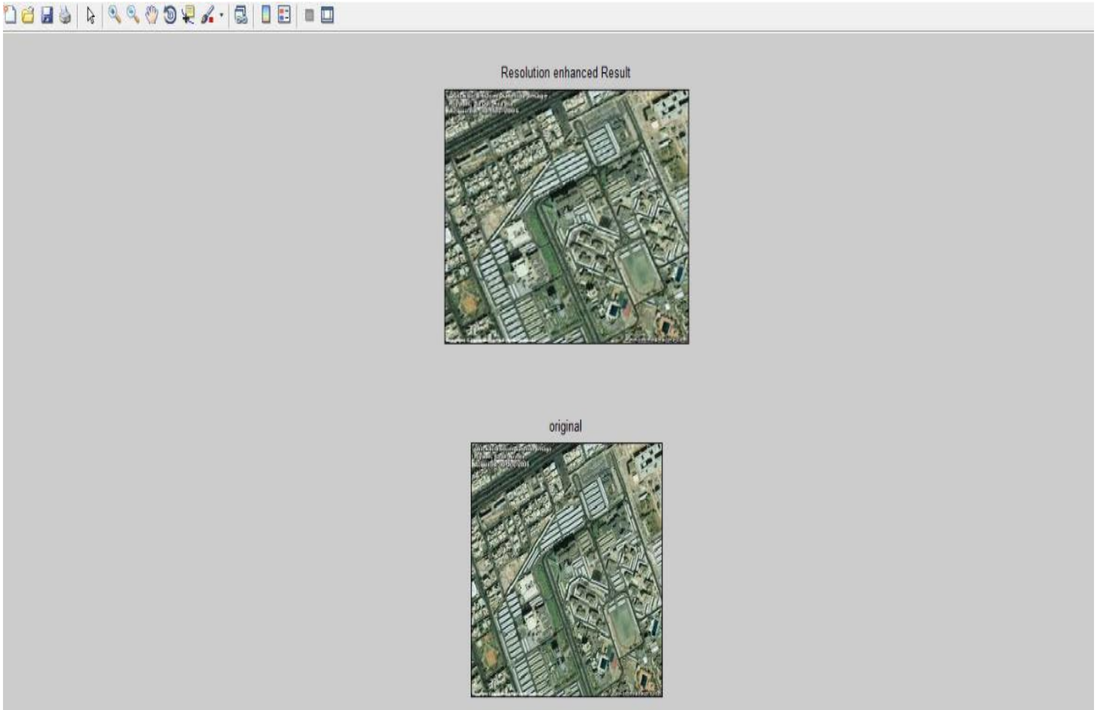

Fig 5.2 Resolution enhanced Image and original image

These images have been obtained after applying Discrete wavelet transform with the original image so as to obtain all the frequency components of the original image. Mr. Mansingh Rathod et.al.[13] utilized Stationary wavelet Transform and Discrete Wavelet Transform in his paper for the satellite image resolution enhancement.

M.Hemalata et. al.[12] provided comparison of DWT,SWT and DT-CWT for nhancement of Low Resolution Satellite Images in terms of peak signal to noise ratio, root mean square error and Pearson Correlation Coefficient.

Algorithm	**MSE**	**PSNR(db)**	**Correlation Coefficient**
DWT	**121.1982**	**27.6871**	**0.9794**

Fig 5.4 Experimental results

The following results have been obtained by using DWT algorithm and Lanczos interpolation for obtaining high Resolution Enhancement of satellite Images.

CHAPTER SIX

Future Work

For future scope, the algorithm for image resolution enhancement using Wavelet Transform along with Lanczos Interpolation can be employed in various areas.

Some of them has been discussed here :

- In our country's defence aircrafts and radars for identification of enemy aircraft, if the image quality of our aircraft will be better, than the enemy aircraft can be visualized easily and effective measures can be taken.

- Similarly for underwater sea applications and SONAR based applications, better quality images will contribute. In Indian navy submarine operations, enhanced resolution images will help in detecting the enemy.

- In traffic monitoring system where images are captured through satellite cameras to detect the real time routes , this algorithm can be effectively used for better quality images.

- For archeological surveys, for exploring the Earth's crust, for soil quality surveys and for exploring the buried fossil fuels underneath, better quality images would serve the purpose.

- In medical field, high resolution images will be useful for diagnosing the disease and evaluating the reports. For surgeries of patients high resolution camera would help a lot.

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