International Journal of Application or Innovation in Engineering & Management (IJAIEM)
Web Site: www.ijaiem.org Email: editor@ijaiem.org, editorijaiem@gmail.com
Volume 2, Issue 9, September 2013 **ISSN 2319 - 4847**

Resolution Enhancement of images with Interpolation and DWT-SWT Wavelet Domain Components

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ABSTRACT

Display resolution sizes are increasing uncontrollably. Imaging system resolution is not catching up with the display technology; this highlights the need for resolution enhancement methods. In this paper we have proposed new method for super resolution. The proposed method uses SWT and DWT high frequency sub bands. PSNR is used as quality measure to compare the proposed method with other methods. Proposed method proves to be superior to other state of the art super resolution methods.

Keywords: -super resolution;wavelet transform; stationary and discrete wavelet.

1. INTRODUCTION

Image resolution is always a key feature for all kinds of images. With ever increasing sizes of the displays need for super resolution images has also been increased. This is also impacted by the limited size of the digital image sensor. Though widespread commercial cameras provide very high resolution images, most of the scientific cameras still have the resolution of only 512 X 512. Resolution enhancement is always being associated with the interpolation techniques. Research suggests that interpolation methods increase the intensity of low frequency components. This means interpolated image will have less number of sharp intensity transactions per pixel. A new method for resolution enhancement which preserves high frequency contents of the image is suggested in the paper.

Spatial domain techniques lag in extraction and preservation of high frequency components of an image. This suggests that some other technique not involving spatial domain is to be used. So the image needs to be converted to some other domain, processed and then converted back to spatial domain. The domain can be Fourier domain, wavelet domain or any other. Fourier domain is more suitable for spectral filtering. The spectral filtering removes particular frequencies from the image. Wavelet domain separates components of an image in to individual matrices. These matrices then can be processed separately and combined together to get the desired result.

Fast algorithms for implementation of discrete wavelet transform have enhanced the use of wavelet domain for image resolution improvement. Various image processing algorithms can be implemented with discrete wavelet transform (DWT)[1]. DWT decomposes image into four sub bands. These sub bands are low-low (LL), low-high (LH), high-low

(HL) and high-high (HH). These sub bands are of . half the dimensions of that of image under consideration. Stationary wavelet transform (SWT) is also being used for the image resolution enhancement [2]. SWT also has four sub bands similar to DWT but sub bands in SWT are of same size of that of the image. Here we have proposed a new method for image resolution enhancement which is based on combination of DWT and SWT components and interpolation. Also we have proved that our proposed technique is better compared to previously available techniques for resolution improvements.

In section II, a literature review for image resolution enhancement techniques has been given. In section III, the proposed method is described in detail. Results are demonstrated in section IV and concluding remarks are presented in section V.

2. Flow Chart Of The Resolution Enhancement Algorithm

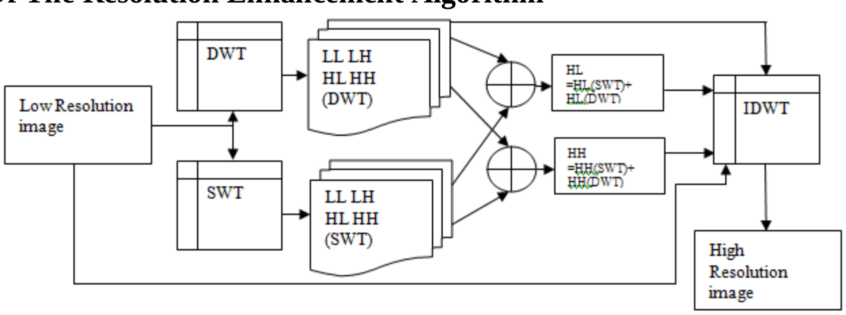

Figure 1 Flow chart of the resolution enhancement algorithm

3. Need Of Image Resolution Enhancement

Resolution of an image has been always an important issue in many image and video-processing applications, such as video resolution enhancement, feature extraction, and satellite image resolution enhancement. Interpolation in image processing is a method to increase the number of pixels in a digital image. Interpolation has been widely used in many image processing applications, such as facial reconstruction, multiple description coding, and image resolution enhancement. The interpolation-based image resolution enhancement has been used for a long time and many interpolation techniques have been developed to increase the quality of this task. There are three well-known interpolation techniques, namely, nearest neighbor, bilinear, and bicubic. Bicubic interpolation is more sophisticated than the other two techniques and produces smoother edges. Wavelets are also playing a significant role in many image-processing applications.

The 2-D wavelet decomposition of an image is performed by applying the 1-D discrete wavelet transform (DWT) along the rows of the image first, and then the results are ecomposed along the columns. This operation results in four decomposed sub band images referred to low-low (LL) low-high (LH), high-low (HL), and high-high (HH). The frequency components of those sub bands cover the full frequency spectrum of the original image. Image resolution using wavelets is a relatively new subject and recently many new algorithms have been proposed. Carey et al have attempted to estimate the unknown details of wavelet coefficients in an effort to improve the sharpness of the reconstructed images. Their estimation was carried out by investigating the evolution of wavelet transform extreme among the same type of sub bands. Edges identified by an edge detection algorithm in lower frequency sub bands were used to prepare a model for estimating edges in higher frequency sub bands and only the coefficients with significant values were estimated as the evolution of the wavelet coefficients. In many researches, hidden Markov has been also implemented in order to estimate the coefficients. In this paper, we propose a resolution-enhancement technique using interpolated DWT high-frequency sub band images and the input low-resolution image. Inverse DWT (IDWT) has been applied to combine all these images to generate the final resolution-enhanced image. In order to achieve a sharper image, we propose to use an intermediate stage for estimating the high- frequency sub bands by utilizing the difference image obtained by subtracting the input image and its interpolated LL sub band. The proposed technique has been compared with standard interpolation techniques, wavelet zero padding (WZP), where the unknown coefficients in high-frequency subbands are replaced with zeros, and state-of-art techniques, such as WZP and cycle- spinning (CS), and previously introduced complex wavelet transform (CWT)-based image resolution enhancement. It is necessary to recall that in this paper the resolution enhancement is used as a process that enlarges the given input in the way that the output is sharper. The performance of the proposed technique over performs all available state-of-art methods for image resolution enhancement. The visual and quantitative results are given in the results and discussions section. In all steps of the proposed satellite image resolution enhancement technique, Daubechies wavelet transform as mother wavelet function and bicubic interpolation as interpolation technique have been used.

3.1 DWT-Based Resolution Enhancement

As it was mentioned before, resolution is an important feature in satellite imaging, which makes the resolution enhancement of such images to be of vital importance as increasing the resolution of these images will directly affect the performance of the system using these images as input. The main loss of an image after being resolution enhanced by applying interpolation is on its high-frequency components, which is due to the smoothing caused by interpolation. Hence, in order to increase the quality of the enhanced image, preserving the edges is essential. In this paper, DWT has been employed in order to preserve the high-frequency components of the image. DWT separates the image into different sub band images, namely, LL, LH, HL, and HH. High frequency sub bands contain the high-frequency component of the image. The interpolation can be applied to these four sub band images. In the wavelet domain, the low-resolution image is obtained by low-pass filtering of the high-resolution image. The low-resolution image (LL sub band), without quantization (i.e., with double-precision pixel values) is used as the input for the proposed resolution enhancement process. In other words, low-frequency sub band images are the low resolution of the original image. Therefore, instead of using low-frequency sub band images, which contains less information than the original input image, we are using this input image through the interpolation process. Hence, the input low-resolution image is interpolated with the half of the interpolation factor, $\alpha/2$, used to interpolate the high-frequency sub bands, as shown in Fig. 5. In order to preserve more edge information, i.e., obtaining a sharper enhanced image, we have proposed an intermediate stage in high-frequency sub band interpolation process.

3.2 SWT- Based Resolution Enhancement

In recent years there is increased demand for better quality images in various applications such as biomedical imaging, surveillance and video enhancement. Image enhancement is also widely useful for satellite image applications which include mine detection, urban planning, military planning, intelligence and disaster monitoring/evaluation. Image resolution and contrast are the two major issues of images in these fields. Images are processed in order to enhance the quality of the digital images.

An image is a picture or photograph and is usually a numeric representation of a two dimensional function. An image is represented by intensity at a particular point whose spatial coordinates are on generally x and y axis coordinates. It is a two dimensional collection of pixel values. The resolution or dimension is often used for a pixel count in digital imaging. In this technique the image is enhanced from a lower resolution (dimension) to a higher resolution (dimension). Contrast is the difference in luminance that makes an object distinguishable. In visual perception of real world, contrast is determined by the difference in color and brightness of the object and the other object within the same field of view. Because the human visual system is more sensitive to contrast than absolute luminance, we can perceive the world similarly regardless of the huge changes in illumination. In this technique, the contrast is enhanced by changing the illumination information of the image.

One of the commonly used techniques for image resolution enhancement is interpolation. Interpolation increases the number of pixels in the digital image. The image interpolation algorithms widely used are bi-cubic interpolation , bilinear interpolation, nearest neighbor interpolation and wavelet zero padding .

Discrete Wavelet Transform (DWT), Stationary wavelet transform (SWT) and integer wavelet transform are three versatile tools for modern image processing. These techniques have various image processing applications such as super resolution , facial reconstruction , multiple description coding and video enhancement .

In the proposed technique bi-cubic interpolation is used. Bi-cubic interpolation looks best with smooth edges and less blurring compared to the other techniques. In the proposed technique SWT and IWT are the two methods used to preserve the high frequency components of the digital image. Integer wavelet transform using lifting scheme is an efficient algorithm to calculate wavelet transform. Also integer wavelet transform using lifting schemes provides a perfect reconstruction.

Low contrast image results due to low light conditions, lack of dynamic range of the camera sensor. Contrast stretching operation results in good quality image. For this, there have been several methods such as general histogram equalization (GHE) , Dynamic histogram equalization (DHE) , Dynamic Histogram Specification (DHS) , Brightness preserved dynamic histogram equalization .GHE is a common technique for enhancing the appearance of the image. It involves finding a grey scale transformation function that creates an output image with a uniform histogram.DHE obtained from dynamic histogram specification generates the specified histogram dynamically from the input image. In the proposed technique image contrast enhancement is done using singular value based image equalization. Here it equalizes the singular value matrix obtained from singular value decomposition.

The proposed technique is compared with other resolution enhancement methods such as

-Wavelet zero padding [WZP].

-DWT based super resolution [DWT SR].

-DWT-SWT based super resolution [DWT-SWT SR].

3.3 Resolution enhancement methods

Image resolution enhancement is the field developed out of interpolation techniques. Different interpolation techniques have been devised for better interpolation of two dimensional data [3-5]. Most widely used spatial interpolation methods are bilinear, bi-cubic and nearest neighbor. These methods lose mainly the high frequency components.

Fourier transform have been used to improve resolution of shaky images, also for improvement of images which are degraded due to blurring. Wavelet domain approaches are widely being used for improvement of resolution of images [1]. Correlation between sub bands of wavelet transform is used to obtain high resolution images [5]. Complex wavelet transform is used for satellite image resolution improvement [4]. Low resolution video improvement technique using DWT is fast but not suitable for super resolution of static images [6]. Combinations of high frequency wavelet sub bands with input image is being used for improving resolutions [7]. Use of combination of SWT and DWT along with original image for resolution enhancement of images was suggested by Hasan Damirel[8]. The proposed method combines high frequency sub bands of DWT and SWT with original image to get super resolved image.

3.4 Image Resolution Enhancement Method Using SWT AND DWT

The main loss in image resolution enhancement by using interpolation is on its high frequency components (i.e., edges), which is due to the smoothing caused by interpolation. Edges plays very important role in image. To increase the quality of the super resolved image, it is essential to preserve all the edges in image. In work, DWT has been employed in order to preserve the high frequency components of the image(i.e. edges). The redundancy and shift invariance of the DWT mean that DWT coefficients are inherently interpolable.

In this topic, one level DWT is used to decompose an input image into different subband images. Three high frequency subbands (LH, HL, and HH) contain the high frequency components of the input image(i.e. edges). In this technique, bicubic interpolation with enlargement factor of 2 is applied to high frequency subband images. Information loss occur due to down sampling in each of the DWT subbands caused in the respective subbands. That is why SWT (Stationary Wavelet Transform) is used to minimize this loss.

The SWT is an inherently redundant scheme as the output of each level of SWT contains the same number of samples as the input – so for a decomposition of N levels there is a redundancy of N in the wavelet coefficients. The interpolated high frequency subbands and the SWT high frequency subbands have the same size which means they can be added with each other. The new corrected high frequency subbands can be interpolated further for higher enlargement. Also it is known that in the wavelet domain, lowpass filtering of the high resolution image produce the low resolution image. In other words, low frequency subband is the low resolution of the original image.

Therefore, instead of using low frequency subband, which contains less information than the original high resolution image, Hasan Demirel and Gholamreza Anbarjafari are using the input image for the interpolation of low frequency subband image. The quality of the super resolved image increases using input image instead of low frequency subband. Fig. illustrates the block diagram of the used image resolution enhancement technique.

By interpolating input image by 3, and high frequency subbands by 2 and in the intermediate and final interpolation stages respectively, and then by applying IDWT, as illustrated in Fig. the output image will contain sharper edges than the interpolated image obtained by interpolation of the input image directly.

This is due to the fact that, the interpolation of isolated high frequency components in high frequency subbands and using the corrections obtained by adding high frequency subbands of SWT of the input image, will preserve more high frequency components after the interpolation than interpolating input.

4. Image Enhancement

Denote a two-dimensional digital image of gray-level intensities by **I**. The image **I** is ordinarily represented in software accessible form as an $M \times N$ matrix containing indexed elements $I(i, j)$, where $0 \leq i \leq M - 1$, $0 \leq j \leq N - 1$. The elements $I(i, j)$ represent samples of the image intensities, usually called *pixels* (*pict*ure *el*ements). For simplicity, we assume that these come from a finite integer-valued range. This is not unreasonable, since a finite wordlength must be used to represent the intensities. Typically, the pixels represent optical intensity, but they may also represent other attributes of sensed radiation, such as radar, electron micrographs, x rays, or thermal imagery.

This allows selective enhancement based on the contrast sensitivity function of the human visual system. We also proposed. An evaluation method for measuring the performance of the algorithm and for comparing it with existing approaches. The selective enhancement of the proposed approach is especially suitable for digital television applications to improve the perceived visual quality of the images when the source image contains less satisfactory amount of high frequencies due to various reasons, including interpolation that is used to convert standard definition sources into high-definition images. Processing can presumably generate new frequency components and thus it is attractive in some applications.

4.1 Automatic image enhancement

Camera or computer image editing programs often offer basic automatic image enhancement features that correct color hue and brightness imbalances as well as other image editing features, such as eye removal, sharpness adjustments, zoom features and automatic cropping. These are called automatic because generally they happen without user interaction or are offered with one click of a button or mouse button or by selecting an option from a menu. Additionally, some automatic editing features offer a combination of editing actions with little or no user interaction.

4.2 Point Operations

Often, images obtained via photography, digital photography, flatbed scanning, or other sensors can be of low quality due to a poor image contrast or, more generally, from a poor usage of the available range of possible gray levels. The images may suffer from overexposure or from underexposure, as in the "mandrill" image. In performing image enhancement, we seek to compute **J**, an enhanced version of **I**. The most basic methods of image enhancement involve *point operations*, where each pixel in the enhanced image is computed as a one-to-one function of the corresponding pixel in the original image: $J(i, j) = f[I(i, j)]$. The most common point operation is the linear contrast stretching operation, which seeks to maximally utilize the available gray-scale range. If a is the minimum intensity value in image **I** and b is the maximum, the point operation for linear contrast stretching is defined by

$$J(i,j) = \frac{K-1}{b-a}[I(i,j) - a] \qquad (1)$$

Assuming that the pixel intensities are bounded by $0 \leq I(i, j) \leq K - 1$, where K is the number of available pixel intensities. The result image **J** then has maximum gray level $K - 1$ and minimum gray level 0, with the other gray levels being distributed in-between according to Eq. (1).

Several point operations utilize the image *histogram*, which is a graph of the frequency of occurrence of each gray level in I. The histogram value $H_I(k)$ equals n only if the image I contains exactly n pixels with gray level k. Qualitatively, an image that has a flat or well-distributed histogram may often strike an excellent balance between contrast and preservation of detail. Histogram flattening, also called *histogram equalization* in Gonzales and Woods (1), may be used to transform an image I into an image J with approximately flat histogram. This transformation can be achieved by assigning

$$J(i,j) = (K-1)P(i,j) \qquad (2)$$

where $P(i, j)$ is a sample cumulative probability formed by using the histogram of I:

$$P(i,j)=\frac{1}{MN}\sum_{k=0}^{I(i,j)}H_1(k) \qquad (3)$$

A third point operation, frame averaging, is useful when it is possible to obtain multiple images G_i, $i = 1, \ldots, n$, of the same scene, each a version of the ideal image I to which deleterious noise has been unintentionally added:

$$\mathbf{G}_i=\mathbf{I}+\mathbf{N}_i \qquad (4)$$

where each noise "image" $\mathbf{N}_i$ is an $M \times N$ matrix of discrete random variables with zero mean and variance σ^2. The noise may arise as electrical noise, noise in a communications channel, thermal noise, or noise in the sensed radiation. If the noise images are not mutually correlated, then averaging the n frames together will form an effective estimate $\hat{\mathbf{I}}$ of the uncorrupted image **I**, which will have a variance of only σ^2/n:

$$\hat{I}(i,j)=\frac{1}{n}\sum_{i=1}^{n}G_i(i,j) \qquad (5)$$

This technique is only useful, of course, when multiple frames are available of the same scene, when the *information* content between frames remains unchanged (disallowing, for example, motion between frames), and when the *noise* content does change between frames. Examples arise quite often, however. For example, frame averaging is often used to enhance synthetic aperture radar images, confocal microscope images, and electron micrographs.

4.3 Linear Filters

Linear filters obey the classical linear superposition property as with other linear systems found in the controls, optics, and electronics areas of electrical engineering (2). Linear filters can be realized by linear convolution in the spatial domain or by pointwise multiplication of discrete Fourier transforms in the frequency domain. Thus, linear filters can be characterized by their frequency selectivity and spectrum shaping. As with 1-D signals, 2-D digital linear filters may be of the low-pass, high-pass or band-pass variety. Much of the current interest in digital image processing can be traced to the rediscovery of the *fast Fourier transform* (*FFT*) some 30 years ago (it was known by Gauss). The FFT computes the discrete Fourier transform (*DFT*) of an $N \times N$ image with a computational cost of $O(N^2 \log_2 N)$, whereas naive DFT computation requires N^4 operations. The speedup afforded by the FFT is tremendous. This is significant in linear filtering-based image enhancement, since linear filters are implemented via convolution:

$$\mathbf{J}=\mathbf{F}*\mathbf{G} \qquad (6)$$

where **F** is the impulse response of the linear filter, **G** is the original image, and **J** is the filtered, enhanced result. The convolution in Eq. (6) may be implemented in the frequency domain by the following pointwise multiplication (·) and inverse Fourier transform (*IFFT*):

$$\mathbf{J}=\mathbf{IFFT}[\mathbf{FFT}(\mathbf{F}_0)\cdot\mathbf{FFT}(\mathbf{G}_0)] \qquad (7)$$

where $\mathbf{F}_0$ and $\mathbf{G}_0$ are $2N \times 2N$ *zero-padded* versions of **F** and **G**. By this we mean that $F_0(i, j) = F(i, j)$ for $0 \le i, j \le N - 1$ and $F_0(i, j) = 0$ otherwise; similarly for $\mathbf{G}_0$. The zero padding is necessary to eliminate wraparound effects in the FFTs which occur because of the natural periodicities that occur in sampled data. If **G** is corrupted as in Eq. (4) and **N** contains white noise with zero mean, then enhancement means noise-smoothing, which is usually accomplished by applying a low-pass filter of a fairly wide bandwidth. Typical low-pass filters include the average filter, the Gaussian filter and the ideal low-pass filter. The average filter can be supplied by averaging a neighborhood (an $m \times m$ neighborhood, for example) of pixels around $G(i, j)$ to compute $J(i, j)$. Likewise, average filtering can be viewed as convolving **G** with a box-shaped kernel **F** in Eq. (7).

5. Interpolation

Interpolation is the process of defining a function that takes on specified values at specified points. This chapter concentrates on two closely related interpolants: the piecewise cubic spline and the shape-preserving piecewise cubic named \pchip.

Interpolation is the process of estimating the values of a continuous function from discrete samples. Image processing applications of interpolation include image magnification or reduction, subpixel image registration, to correct spatial distortions, and image decompression, as well as others. Of the many image interpolation techniques available, nearest neighbour, bilinear and cubic convolution are the most common, and will be talked about here. Sinc Interpolation provides a perfect reconstruction of a continuous function, provided that the data was obtained by uniform sampling at or above the Nyquist rate. Sinc Interpolation does not give good results within an image processing environment, since image data is generally acquired at a much lower sampling rate. The mapping between the unknown high-resolution image and the low-resolution image is not invertible, and thus a unique solution to the inverse problem cannot be computed. One of the essential aspects of interpolation is efficiency since the amount of data associated with digital images is large.

6. Proposed Method

Super resolved images are characterized by the high frequency content of those images. High frequency components signify the edges and minute details spread all over the image. We have used components of DWT and SWT to preserve high frequency components. Properties of DWT make it interpolable [2]. Daubechies wavelet function is used to calculate DWT of the image. DWT gives four sub bands; three of these four sub bands contain high frequency contents of an image. High frequency sub band images (LH, HL and HH) are enlarged by a factor of 2 using bicubic interpolation. This adds redundant information to DWT sub band images. Redundancy in information can be covered with addition of SWT sub bands (HL and HH). SWT sub bands are of the same size of that of the image (two times of the size of DWT sub bands).
Interpolated sub bands of DWT and SWT sub bands can be added together as they have the same size. LL sub band of wavelet domain is low pass filtered part of high frequency sub band. This means original image is rich in information compared to that of LL component. Instead of using LL component for getting inverse discrete wavelet transform we have used original image. This gives more detail information as compared to that of IDWT with LL component.Detailed flow chart of the image resolution enhancement with proposed method is shown in figure 1. As shown in figure 1 high frequency sub bands of DWT are interpolated by to get sub bands of same size as that of image. Input image and three components are used as input to IDWT which gives super resolution image.

7. Results and Discussions

Proposed method has been tested with standard set of test images. The input images of resolution 128x128 are used, which are super resolved to 512x512. Due to the space limitations we are only showing the results obtained with images of peppers and Lena. As shown in figure 2 , original image along with high resolution images obtained by various super resolution techniques are shown. Subjective evaluation shows that the proposed method works better than any prior methods. Edges and other minute details are more enhanced in our method. Close observation of sub-figures of figure 2, 3 and 4 reveals that proposed method and SDWT results are very much the same in smooth parts of image (low frequency parts) but high frequency content of proposed method seems to be better resolved.
Objective evaluation of quality of resolution enhancement is also been done. PSNR is used as a quality measure. PSNR of the images of baboon, Lena and peppers with bilinear, bicubic, nearest neighbor interpolation, SDWT SR and proposed method are listed in table I. We have not mentioned the PSNR for all the previous methods as SDWT- SR is superior in PSNR compared to state of the art methods[9]. Table I shows proposed methods superiority over spatial and wavelet domain techniques.

Table 1: PSNR of resolution enhanced images

Method	Pepper	Lena
Bilinear	25.73	28.73
Bicubic	25.80	28.78
Nearest Neighbour	26.04	28.87
SDWT	26.60	31.17
Proposed Method	26.96	37.20

Figure 2 Pepper and Lena Image a) and its resolution enhanced outputs with : b) Bilinear Interpolation, c) Bicubic Interpolation, d) Nearest Neighbor Interpolation, e) SDWT f) Proposed method

8. Conclusion

This paper has proposed a new method for obtaining super resolution images from low resolution images. The proposed method is much better than previous methods. We have also provided subjective and objective comparison of the resultant images. Proposed method involves calculation of DWT sub bands. High frequency sub bands are interpolated to double their size. DWT loses some information in the process of interpolation; it is corrected with the help of SWT. IDWT with original image and high frequency components give super resolution image. We have compared proposed method with state of the art methods. PSNR table shows the superiority of the proposed method.

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