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Better Perception of Low Resolution Images Using Wavelet Interpolation Techniques

Tarun Gulati, Kapil Gupta, Dushyant Gupta

***Abstract*—**High resolution images are always desired as they contain the more information and they can better represent the original data. So, to convert the low resolution image into high resolution interpolation is done. The quality of such high resolution image depends on the interpolation function and is assessed in terms of sharpness of image. This paper focuses on Wavelet based Interpolation Techniques in which an input image is divided into subbands. Each subband is processed separately and finally combined the processed subbandsto get the super resolution image.

***Keywords*—**SWT, DWTSR, DWTSWT, DWCWT

I. Introduction

THE need for super resolution images has been increased with the increasing sizes of the displays. Image super resolution refers to image processing algorithms that produce high quality, High-Resolution (HR) images from a set of low-quality, Low-Resolution (LR) images [1], [2]. Better-quality images are always demanded. In any visual applications, the imaging sensors have poor resolution outputs due to the limited size of the digital image sensor. So, super resolution algorithms are used when resolution cannot be improved by replacing sensors, either because of cost or hardware physical limits. Resolution enhancement is always being associated with the interpolation techniques. Intensity of low frequency components can be increased by interpolation methods. Spatial domain techniques lag in extraction and preservation of high frequency components of an image. So, first of all the image is converted to some other domain and then image is processed and finally converts the processed image back into spatial domain. The domain used for processing can be Fourier domain, Wavelet domain or any other. For spectral filtering Fourier domain is more suitable. Particular frequencies are removed from the image in spectral filtering; on the other hand Wavelet domain separates components of an image into individual matrices. These matrices then can be processed separately and combined together to get the desired result. A number of image processing algorithms can be implemented with Discrete Wavelet Transform (DWT). Discrete Wavelet Transform decomposes image into four subbands. These subbands are Low-Low (LL), Low-High (LH), High-Low (HL) and High-High (HH). The dimension of these subbands is half of the dimension of image under consideration. Stationary Wavelet transform (SWT) is also being used for the image resolution enhancement. SWT also has four subbands similar to DWT but subbands in SWT are of the same size of that of the image. In Section II, a literature review of wavelet based interpolation techniques has been given. In Section III, the methodology used in the above said technique is described in detail. Results are demonstrated in Section IV and concluding remarks are presented in Section V.

Tarun Gulati is a Research Scholar in M.M.University, Mullana, Ambala, India (e-mail: gulati_tarun@rediffmail.com).

Dr. Kapil Gupta is Assoc. Prof. in Department of Electronics and Communication Engineering in M.M.University, Mullana, Ambala, India (e-mail: kapil_mbm@yahool.com).

Dr. Dushyant Gupta is a Prof. in Electronics Department in University College, Kurukshetra University, Kurukshetra, India (e-mail: dgupta@kuk.ac.in).

II. Key Literature Review

Many researchers and engineers have proposed and implemented algorithms for improving the performance of the above mentioned techniques. This section presents a review of related research done over the last decade.

Alptekin et al. [3] presented a wavelet domain image resolution enhancement algorithm using zero-padding in the wavelet domain which is further processed using the cycle-spinning methodology which reduces ringing and finally Linear regression using a minimal training set of high-resolution originals was employed to rectify the degraded edges. Dumic et al. [4] presented a method that utilizes the theory of projection onto convex sets (POCS) with a new projection operator based on Discrete Wavelet Transformation for reducing blurring artifacts. Numan et al. [5] proposed a wavelet-based dynamic range compression algorithm to improve the visual quality of digital images captured in the high dynamic range scenes with non-uniform lighting conditions. Turgay et al. [6] proposed a complex wavelet-domain image resolution enhancement algorithm based on the estimation of wavelet coefficients. The method uses forward and inverse Dual-Tree Complex Wavelet Transform (DT-CWT) to construct the high-resolution image from the given low-resolution image. Gholamreza et al. [7] proposed a super-resolution technique based on interpolation of the high-frequency subband images obtained by discrete wavelet transform and the input image. Hasan et al. [8] proposed a satellite image resolution enhancement technique based on interpolation of the high-frequency subband images obtained by dual-tree complex wavelet transform. Hasan et al. [9] proposed a new satellite image contrast enhancement technique based on the discrete wavelet transform and singular value decomposition. Prakash et al. [10] proposed a new learning-based approach for super-resolving an image captured at low spatial resolution. Highresolution estimate is obtained by learning the high-frequency details from the available database. Hasan et al. [11] proposed an image resolution enhancement technique based on interpolation of the high frequency subband images obtained by discrete wavelet transform and the input image. The edges are enhanced by introducing an intermediate stage by using stationary wavelet transform. Karthikeyan[12] proposed three techniques for edge enhancement, image enlargement and image fusion. All the algorithms have the common goal of improving the visual quality of ultrasonic images and are based on wavelets and other image processing techniques. Ramdas et al. [13] mentioned that there are many traditional image interpolation techniques such as Bilinear Interpolation, Nearest Neighbor Interpolation, Bicubic Interpolation and Lanczos Interpolation.However, in comparison to all traditional methods, the image resolution enhancement method using Wavelet Transform gives better result. Mayuri D Patil et al. [14] used DTCWT technique to improve the resolution of satellite images. Sangeetha et al. [15] proposed an image resolution enhancement technique based on interpolation of the high frequency subband images obtained by discrete wavelet transform and the input image. The edges are enhanced by introducing an intermediate stage using stationary wavelet transform. P. Karunakar et al. [16] proposed a satellite image resolution enhancement technique based on the interpolation of the high frequency subbands obtained by discrete wavelet transform and the input image. The proposed resolution enhancement technique uses DWT to decompose the input image into different sub bands. Then, the high frequency subband images and the input low-resolution image have been interpolated, followed by combining all these images to generate a new enhanced resolution image using inverse DWT. In order to achieve a sharper image, an intermediate stage for estimating the high-frequency sub bands has been proposed.

III. Methodology

The high-frequency component (i.e. the edges) is a key loss of an image after being super-resolved by applying interpolation. This loss occurs due to the smoothing caused by interpolation. Preserving the edges is essential to increase the quality of a super-resolved image. Therefore, [8] proposed a super-resolution technique based on interpolation of the high-frequency subband images obtained by Discrete Wavelet Transform (DWT) of the input image, as shown in Fig. 1. This technique uses DWT to decompose an image into different subband images; namely, Low-Low (LL), Low-High (LH), High-Low (HL), and High-High (HH). These subband images contain the high-frequency components of the input image. In this technique, the interpolation is applied to high-frequency subband images as well as the input image. Finally, the IDWT of the interpolated subband images and the input image produce the final high-resolution output image. In this technique, the employed interpolation method is same for all subband and input images. Also in this technique, the interpolation and wavelet functions are the two important factors in determining quality of the super-resolved images. The continuous wavelet transform is defined as:

$$CWT_x^{\psi}(\tau,s) = \psi_x^{\psi}(\tau,s) = \frac{1}{\sqrt{|s|}}\int x(t)\,\psi^*\left(\frac{t-\tau}{s}\right)dt \qquad (1)$$

where, the basis function is defined as:

$$\psi_{t,s}(t) = \frac{1}{\sqrt{|s|}}\psi\left(\frac{t-\tau}{s}\right) \qquad (2)$$

and, $\psi(t)$ is the mother wavelet. The transformed signal is a function of two variables, $\tau$and s, the translation and scale parameters, respectively. The wavelet analysis is done in such a way that the signal is multiplied with a function, ($\psi(t)$ the wavelet) and the transform is computed separately for different segments of the time-domain signal. The term translation is related to the location of the window as the window is shifted through the signal. This term corresponds to time information in the transform domain. Instead of a frequency parameter, a scale parameter which is defined as (1/frequency) is used. The parameter scale in the wavelet analysis is similar to the scale used in maps. In terms of frequency, low frequencies (high scales) correspond to a global information of a signal (that usually spans the entire signal); whereas, high frequencies (low scales) correspond to a detailed information of a hidden pattern in the signal (that usually lasts a relatively short time). The discrete wavelet transform is used when dealing with digital images, as shown in Fig. 1.

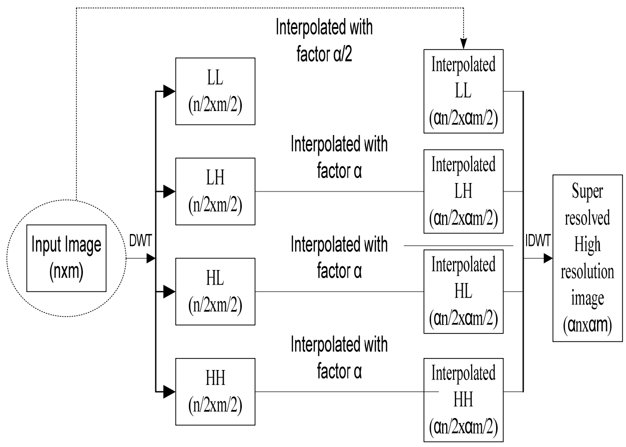


Fig. 1 Block diagram of DWT-SR method

In Fig. 1, DWT is used to decompose an image into different subband images. The high-frequency subband images and the input low-resolution image are then interpolated, followed by combining all these images to generate a new super-resolved image using inverse DWT. The benefit in this scheme is that this super-resolution process considers the higher and lower frequency components which are not taken into account in direct interpolation. Following the DWT technique, [7] proposed another technique to enhance the resolution of satellite images based on interpolation of high-frequency subband images obtained by Dual-Tree Complex Wavelet Transform (DT-CWT). This method uses DT-CWT to decompose an input low-resolution satellite image into different subband images and interpolates input images followed by combining all these images to generate high-resolution images using inverse DT-CWT, as shown in Fig. 2. The DT-CWT-SR method shown in Fig. 2 has the disadvantage of having poor sharpness in edges. Therefore to enhance the edges, another technique is proposed by introducing an intermediate stage using Stationary Wavelet Transform (SWT). DWT is applied in order to decompose an input image into different subbands. Then the high frequency subbands as well as the input image are interpolated. The estimated high frequency subbands are modified using high frequency subband obtained through SWT. Then all these subbands are combined to generate a new high resolution image using Inverse DWT (IDWT). Fig. 3 shows block diagram of this method.

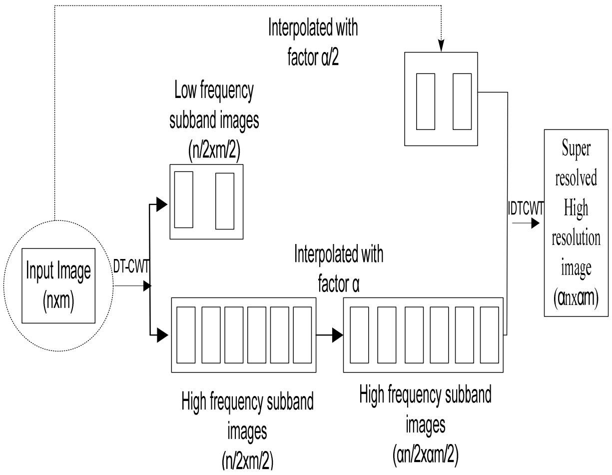


Fig. 2 Block diagram of DT-CWT method

In Fig. 3, the information loss occurs due to down sampling in each of the DWT subbands caused in the respective subbands. This is why SWT is used to minimize this loss. It is because; 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. It is also 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, [8] used 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.

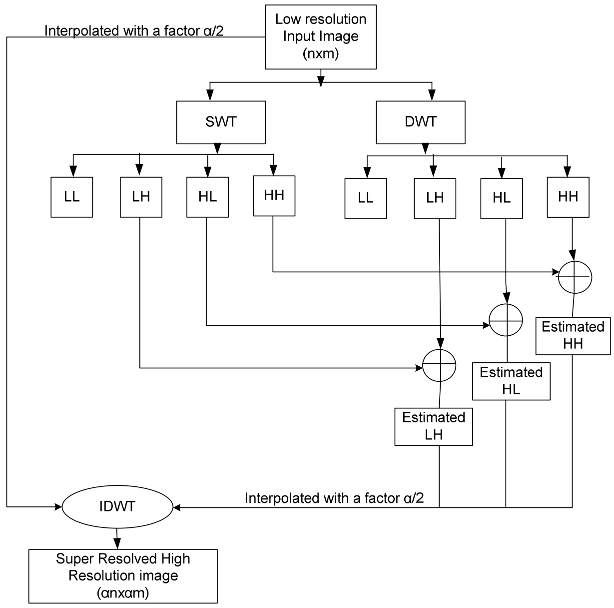


Fig. 3 Block diagram of DWTSWT

IV. Results And Discussion

Various Wavelet based interpolation methods DWTSR, DWTSWT and DTCWT are implemented in MATLab. A MRI image of skull is taken to investigate the effect of above mentioned Wavelet based Interpolation Techniques. The image is resized to 50%. This reduced size image is then zoomed to its original size using various Wavelet based Interpolation techniques as shown in Fig. 4. The parameters used for the evaluation of various techniques are processing time, PSNR, MSE, SSIM, Mutual information and SNR. These parameters are evaluated for the above mentioned techniques and tabulated in Table I. It is found that DWTSWT technique takes lesser time in comparison to other methods for zooming the reduced image to its original size but the SNR and PSNR values of DTCWT is higher than other methods. So, the MSE is found to be less in DTCWT technique. Also Structural Similarity Index (SSIM) and Mutual Information (MI) are higher in case of DTCWT method. The graphs are plotted between various parameters for different Wavelet based Interpolation methods DWTSR, DWTSWT and DTCWT as shown in Fig. 5.

V. Conclusion

From the above said discussion, it is concluded that the processing time of DWTSWT technique is lesser than all other techniques but this technique has accuracy disadvantage. The drawbacks of DWTSWT are overcome in DTCWT. PSNR, MSE, SNR, MI and SSIM of DTCWT technique is better than all other techniques except processing time. So, it is concluded that DTCWT is the best Wavelet based edge interpolation technique if processing time is not a major issue.

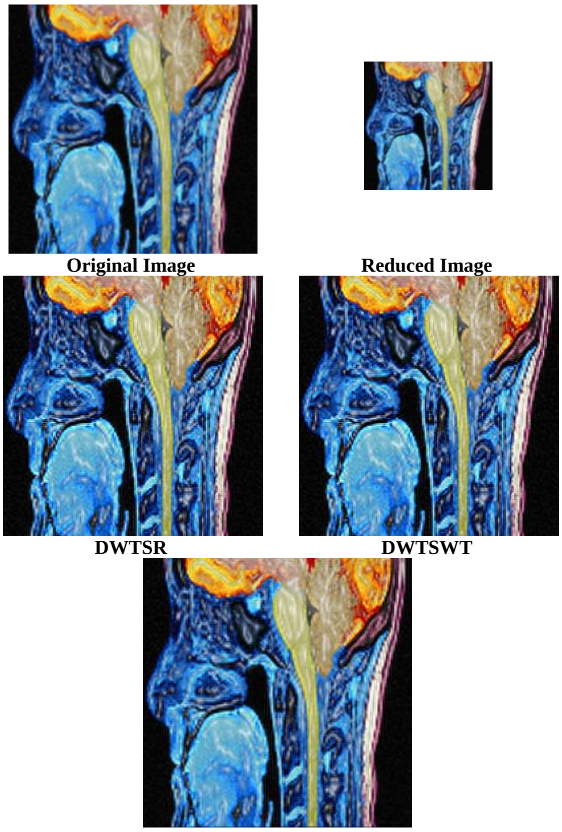
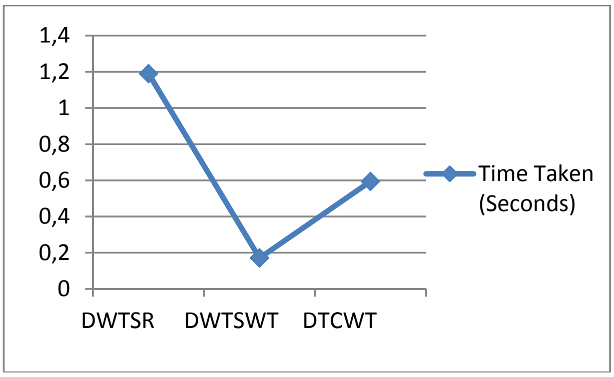


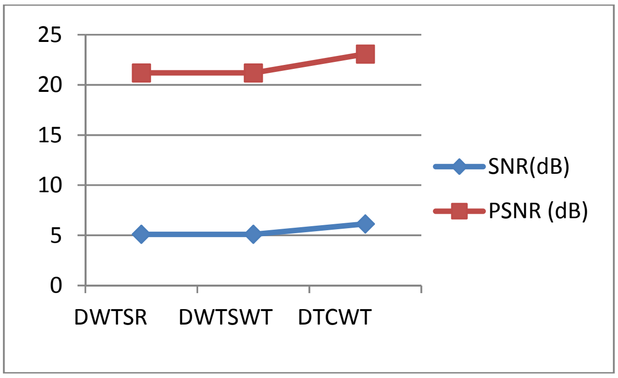
Fig. 4 Results of various Wavelet Based interpolation techniques

TABLE I
COMPARISON OF VARIOUS WAVELET BASED INTERPOLATION TECHNIQUES

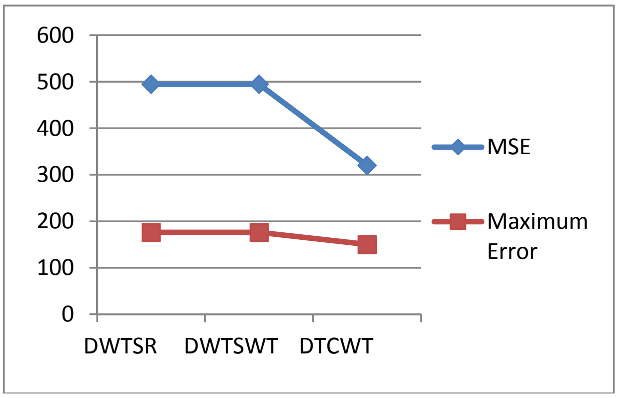
PARAMETERS	ALGORITHM		
	DWTSR	DWTSWT	DTCWT
Time Taken	1.1898	0.1706	0.5938
PSNR	21.1892	21.1892	23.0782
MSE	494.4904	494.4904	320.0848
Maximum MSE	176	176	150
SSIM	0.7845	0.7845	0.8289
Mutual Information	2.0812	2.0812	2.3694
SNR	5.0917	5.0917	6.1328



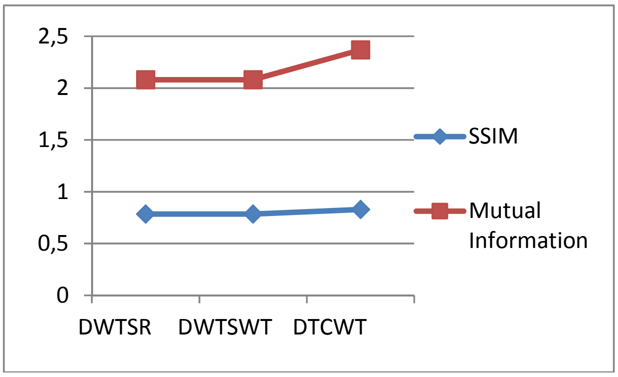
(a)



(b)



(c)



(d)

Fig. 5 The result of various parameters for different wavelet based interpolation techniques

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