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Phase-Adaptive Superresolution of Mammographic Images Using Discrete and Stationary Wavelets

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Abstract: In this correspondence describes a new superresolution approach for enhancing the resolution of mammographic images using Discrete wavelets and Stationary wavelets. This method allows regions of interest of a mammographic image to be viewed in enhanced resolution while reducing the patient exposure to radiation. The proposed method exploits the structural characteristics of breast tissues being imaged and produces higher resolution mammographic images with resolution enhancement technique based on interpolation of the high frequency subband images obtained by discrete wavelet transform (DWT) and the input image. The edges are enhanced by introducing an intermediate stage by 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 being modified by using high frequency subband obtained through SWT. Then all these subbands are combined to generate a new high resolution image by using inverse DWT (IDWT).

Keywords: Discrete wavelet transform, image super resolution, stationary wavelet transform.

I. INTRODUCTION

Breast cancer is one of the most common types of cancer and is one of the leading causes of cancer death worldwide. To reduce the risk of death due to breast cancer, it is important to detect and treat breast cancer in its early stages. One of the most effective methods for detecting breast cancer is through the use of mammography, where a breast radiograph is acquired and analyzed for possible signs of abnormality, such as the presence of masses and micro-calcifications. Some important factors to consider in digital mammography are radiation dosage and image quality. It is important to minimize the patient exposure to radiation. However, low radiation dosage can lead to low signal-to-noise ratios (SNR), which affects image quality. To improve SNR, larger detector pixel dimensions can be used but at the expense of image resolution. Fortunately, the image resolution can be enhanced by multiframe registration techniques. In particular, Robinson et al. [7] showed that mammographic images with similar quality as a single image acquired at a normal dosage of 226 mAs, can be produced using multiple images at a reduced combined dosage of 169.5 mAs. In this case, a set of spatially shifted low radiation images are acquired, and a higher resolution image is composed representing the registered image set.

In practice, the image shifts can be obtained by X-ray tube rotations, or by moving the imaged object with respect to the X-ray source. Also, in some cases, the shifted images are acquired by a set of sensors spatially displaced [8]. The key advantage to this approach is that high-resolution mammographic images can be obtained by combining lower radiation images. As such, multisource superresolution reconstruction is a promising algorithmic solution for obtaining mammographic images with resolutions higher than can be achieved by the physical radiographic hardware in a single image at a given dosage, thereby improving the visibility of suspicious structures. Multisource superresolution reconstruction techniques also can help avoiding patient discomfort, and additional X-ray exposure, when suspicious breast structures are re-examined in higher detail, providing higher quality image scaling than other available methods, as discussed later in this correspondence.

Resolution has been frequently referred as an important aspect of an image. Images are being processed in order to obtain more enhanced resolution. One of the commonly used techniques for image resolution enhancement is Interpolation. Interpolation has been widely used in many image processing applications such as facial reconstruction [1], multiple description coding [2], and super resolution [3]–[6]. There are three well known interpolation techniques, namely nearest neighbor interpolation, bilinear interpolation, and bicubic interpolation.

Image resolution enhancement in the wavelet domain is a relatively new research topic and recently many new algorithms have been proposed [4]–[7]. Discrete wavelet transform (DWT) [8] is one of the recent wavelet transforms used in image processing. DWT decomposes an image into different subband images, namely low-low (LL), lowhigh (LH), high-low (HL), and high-high (HH). Another recentwavelet transform which has been used in several image processing applications is stationary wavelet transform (SWT) [9]. In short, SWT is similar to DWT but it does not use down-sampling, hence the subbands will have the same size as the input image.

II PROBLEM FORMULATION

The multisource image superresolution problem can be formulated in the context of mammographic images as follows. Consider n 2-D low-resolution mammographic images $f_1\, f_2\, f_3\ \cdots\cdots\cdots\ f_n$ of size M x N. Each low-resolution image can be viewed as being acquired from a single high-resolution source image ***g*** of size RM x RN (where R is the resolution enhancement factor), under various forms of signal degradation such as decreased sampling, warping, and blurring. Lowresolution images can undergo different degradations, and a low-resolution image ***f,*** is represented in the following matrix-vector form:

$$(f_i) = H_i(q) + n_i \qquad (1)$$

where f_i is a [MN x 1] vector representing a low-resolution image lexicographically ordered, ***g*** is a $[R^2MN \text{ x } 1]$ vector representing the high-resolution image g lexicographically ordered, H_i is a $[MN \text{ x } \mathrm{R}^2MN]$ matrix representing the degradation function for a low-resolution image, and n_i is a [MN x 1] noise vector added to a low-resolution image.

The degradation function typically is composed of multiple degradation functions, modeling different types of image degradation and can be derived based on the characteristics of the imaging device. The relationship between all low-resolution images and the high resolution image can then be expressed as follows:

$$\begin{bmatrix} (\underline{f}_1)_: \\ (\underline{f}_2)_: \\ \vdots \\ (\underline{f}_n)_: \end{bmatrix} = \begin{bmatrix} \mathrm{H}_1 \\ \mathrm{H}_2 \\ \vdots \\ \mathrm{H}_n \end{bmatrix} (\underline{g})_: + \begin{bmatrix} \underline{n}_1 \\ \underline{n}_2 \\ \vdots \\ \underline{n}_n \end{bmatrix} . \qquad (2)$$

For the sake of simplicity, (2) can be expressed in the following form:

$$\overline{\underline{f}} = \overline{\mathrm{H}}(\underline{g})_: + \overline{\underline{n}} \qquad (3)$$

Where $\bar{f}$ indicates a vector composed of vectors $f_1\, f_2\, f_3\ \cdots\cdots\cdots\ f_n$ Stacked on top of each other, and indicates a matrix composed of matrices $H_1\, H_2\ \cdots\cdots\cdots\ H_n$ stacked on top of each other. Using the above relationship between the low-resolution image and the source high-resolution image, the multisource image superresolution problem can be formulated as an inverse problem, where a model of the high-resolution source image is derived from the observed low-resolution images $f_1\, f_2\, f_3\ \cdots\cdots\cdots\ f_n$ This multisource image superresolution problem is underdetermined, and no unique solution exists.

III PROPOSED IMAGE RESOLUTION ENHANCEMENT

In image resolution enhancement by using interpolation the main loss is on its high frequency components (i.e., edges), which is due to the smoothing caused by interpolation. In order to increase the quality of the super resolved image, preserving the edges is essential. In this work, DWT has been employed in order to preserve the high frequency components of the image. The redundancy and shift invariance of the DWT mean that DWT coefficients are inherently interpolable [9].

In this work, we are proposing an image resolution enhancement technique which generates sharper high resolution image. The proposed technique uses DWT to decompose a low resolution image into different subbands. Then the three high frequency subband images have been interpolated using bicubic interpolation. The high frequency subbands obtained by SWT of the input image are being incremented into the interpolated high frequency subbands in order to correct the estimated coefficients. In parallel, the input image is also interpolated separately. Finally, corrected interpolated high frequency subbands and interpolated input image are combined by using inverse DWT

(IDWT) to achieve a high resolution output image. The proposed technique has been compared with conventional and state-of-art image resolution enhancement techniques. The conventional techniques used are the following:

- ➔ interpolation techniques: bilinear interpolation and bicubic interpolation;
- ➔ wavelet zero padding (WZP).

The state-of-art techniques used for comparison purposes are the following:

- ➔ regularity-preserving image interpolation [7];
- ➔ new edge-directed interpolation (NEDI) [10];
- ➔ hidden Markov model (HMM) [11];
- ➔ HMM-based image super resolution (HMM SR) [12];
- ➔ WZP and cycle-spinning (WZP-CS) [13];
- ➔ WZP, CS, and edge rectification (WZP-CS-ER) [14];
- ➔ DWT based super resolution (DWT SR) [15];
- ➔ complex wavelet transform based super resolution (CWT SR) [5].

According to the quantitative and qualitative experimental results, the proposed technique over performs the aforementioned conventional and state-of-art techniques for image resolution enhancement.

In this correspondence, 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. In the proposed technique, bicubic interpolation with enlargement factor of 2 is applied to high frequency subband images. Downsampling in each of the DWT subbands causes information loss in the respective subbands.

That is why SWT is employed to minimize this loss. 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, the low resolution image is obtained by lowpass filtering of the high resolution image [16].

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, we are using the input image for the interpolation of low frequency subband image. Using input image instead of low frequency subband increases the quality of the super resolved image. Fig. 1 illustrates the block diagram of the proposedimage resolution enhancement technique.

By interpolating input image by α/2, and high frequency subbands by 2 and α in the intermediate and final interpolation stages respectively, and then by applying IDWT, as illustrated in Fig. 1, the output image will contain sharper edges than the interpolated image obtained by interpolation of the input image directly. The proposed technique uses DWT to decompose a low resolution image into different subbands. Then the three high frequency subband images have been interpolated using bicubic interpolation. The high frequency subbands obtained by SWT of the input image are being incremented into the interpolated high frequency subbands 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 image directly. This is particularly important in enhancing mammographic images, where the structural detail of the breast region being imaged.

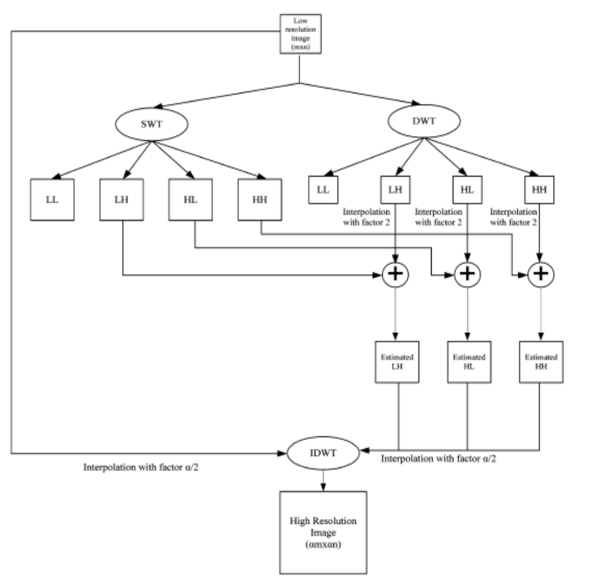

Fig.1. Block diagram of the proposed super resolution algorithm.

Image enhancement operations improve the qualities of an image like improving the image's contrast and brightness characteristics, reducing its noise content, or sharpen the details. This just enhances the image and reveals the same information in more understandable image. It does not add any information to it. Image restoration like enhancement improves the qualities of image but all the operations are mainly based on known, measured, or degradations of the original image. Image restorations are used to restore images with problems such as geometric distortion, improper focus, repetitive noise, and camera motion. It is used to correct images for known degradations.

Image analysis operations produce numerical or graphical information based on characteristics of the original image. They break into objects and then classify them. They depend on the image statistics. Common operations are extraction and description of scene and image features, automated measurements, and object classification. Image analyze are mainly used in machine vision applications.

Note that the input low resolution images have been obtained by down-sampling the original high resolution images. In order to show the effectiveness of the proposed method over the conventional and state-of-art image resolution enhancement techniques, four well-known test images (Lena, Elaine, Baboon, and Peppers) with different features are used for comparison. Table I compares the PSNR performance of the proposed technique using bicubic interpolation with conventional and state-of-art resolution enhancement techniques: bilinear, bicubic, WZP, NEDI, HMM, HMM SR, WZP-CS, WZP-CS-ER, DWT SR, CWT SR, and regularity-preserving image interpolation. Additionally, in order to have more comprehensive comparison, the performance of the super resolved image by using SWT only (SWT-SR) is also included in the table. The results in Table I indicate that the proposed technique over-performs the aforementioned conventional and state-of-art image resolution enhancement techniques. Table I also indicates that the proposed technique over-performs the aforementioned conventional and state-of-art image resolution enhancement techniques.

The estimated high-resolution image is projected onto each constraint within the convex constraint set until the desired condition is satisfied. Other super-resolution methods include maximum a posteriori methods [7], [9], Bayesian methods [10], neural network methods [11], and wavelet-based methods [12]. One major drawback to existing methods is that they treat all image content equally from a structural perspective. This leaves enhancing the visual fidelity of the high-resolution medical images based on the structural characteristics of the underlying image content largely unexplored. This is particularly important in enhancing mammographic images, where the structural detail of the breast region being imaged is critical to the early clinical diagnosis of cancer, improving the chances of success of breast cancer treatments.

Table I

Psnr (Db) Results For Resolution Enhancement From 128x128 To 512x512 Of The Proposed Technique Compared With The Conventional And State-Of-Art Image Resolution Enhancement Techniques

	PSNR (dB)			
Techniques \ images	**Lena**	**Elaine**	**Baboon**	**Peppers**
Bilinear	26.34	25.38	20.51	25.16
Bicubic	26.86	28.93	20.61	25.66
WZP (db. 9/7)	28.84	30.44	21.47	29.57
Regularity-Preserving Image Interpolation[7]	28.81	30.42	21.47	29.57
NEDI [10]	28.81	29.97	21.18	28.52
HMM [11]	28.86	30.46	21.47	29.58
HMM SR [12]	28.88	30.51	21.49	29.60
WZP-CS [13]	29.27	30.78	21.54	29.87
WZP-CS-ER [14]	29.36	30.89	21.56	30.05
DWT SR [15]	34.79	32.73	23.29	32.19
CWT SR [5]	33.74	33.05	23.12	31.03
SWT SR	32.01	31.25	22.74	29.46
Proposed Technique	**34.82**	**35.01**	**23.87**	**33.06**

IV SIMULATION RESULTS

INPUT IMAGE

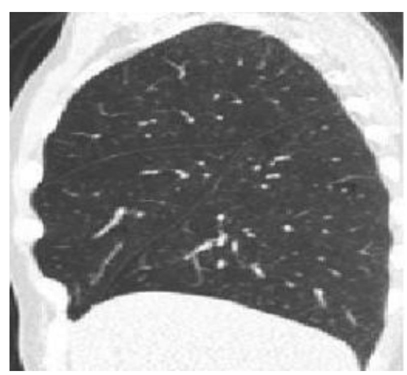

Fig2: Input Image

Fig3: Image Enhancement using Bi-cubic Interpolation Method

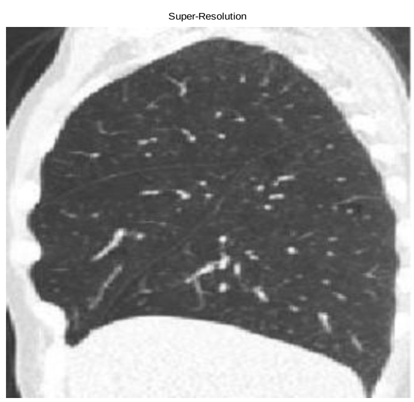

Fig4: Image Enhancement using Super-Resolution Method

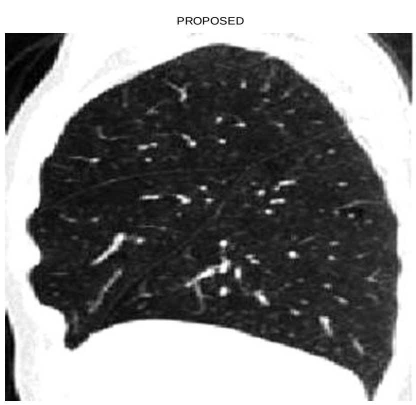

Fig5: Image Enhancement using PROPOSED Method

V. CONCLUSION

This work proposed an image resolution enhancement technique based on the interpolation of the high frequency subbands obtained by DWT, correcting the high frequency subband estimation by using SWT high frequency subbands, and the input image. The proposed technique uses DWT to decompose an image into different subbands, and then the high frequency subband images have been interpolated. The interpolated high frequency subband coefficients have been corrected by using the high frequency subbands achieved by SWT of the input image. An original image is interpolated with half of the interpolation factor used for interpolation the high frequency subbands. Afterwards all these images have been combined using IDWT to generate a super resolved imaged. The proposed technique has been tested on well-known benchmark images, where their PSNR and visual results show the superiority of proposed technique over the conventional and state-of-art image resolution enhancement techniques.

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