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IMPROVING IMAGE QUALITY OF DIGITAL MAMMOGRAPHIC IMAGES USING AN UNDECIMATED DISCRETE WAVELET TRANSFORM METHOD: PERFORMANCE ASSESSMENT

Eri Matsuyama[1], *Du-Yih Tsai*[1], *Yongbum Lee*[1], *Haruyuki Watanabe*[1],
Masaki Tsurumaki[2], *and Katsuyuki Kojima*[3]

[1] Department of Radiological Technology, Graduate School of Health Sciences, Niigata University, 2-746, Asahimachi-dori, Chuo-ku, Niigata, 951-8518, Japan
[2] Department of Radiology, Nakajo Central Hospital, Tainai-shi, Niigata, 959-2656, Japan
[3] Department of Business Administration, Graduate School of Business Administration, Hamamatsu University, 1230, Miyakodacho, Kita-ku, Hamamatsu, 431-2102, Japan

Abstract: Improving image quality in digital mammographic images has clinical impact in order to increase accuracy of detection of breast cancer. This study aimed to develop and evaluate a new method for denoising mammographic images. The features of the proposed method include iterative use of undecimated multi-directional wavelet transforms at adjacent scales. In this method, computer-based simulations have been carried out for selecting wavelet basis function based on mutual information metric. Perceptual experiments on clinical mammograms were conducted. This new method was compared with the conventional methods to demonstrate its superiority.

Keywords: medical imaging, mammograms, wavelet transform, image quality, denoising

1. INTRODUCTION

Mammography is one of the most effective and reliable methods for early breast cancer detection and diagnosis [1-3]. However, it is still far from being ideal. One of the major reasons is due to the presence of noise and subsequently resulting in detection failure or misdiagnosis. Hence noise reduction is one of the major tasks in improving image quality in digital mammographic images. Because of the importance of noise reduction from mammographic images, there has been an enormous amount of research dedicated to the subject of noise removal [4-9].

In this study, we proposed an effective denoising method to attempt to reduce the noise in mammographic images. The method was based on using hierarchical correlation of the coefficients of discrete stationary wavelet transforms [10-13]. The features of the proposed technique include iterative use of undecimated multi-directional wavelet transforms at adjacent scales.

To validate the proposed method, computer simulations were conducted, followed by its applications to clinical mammograms. Mutual information originating from information theory was used as an evaluation measure in this study. Moreover, we conducted a perceptual evaluation of the processed images obtained from the proposed method and other conventional methods for confirmation of the effectiveness of the proposed approach.

2. METHODS AND MATERIALS

The undecimated discrete wavelet transform has been discovered for various purposes and under different names, *e.g.* the shift/translation invariant wavelet transform, the stationary wavelet transform, or the redundant wavelet transform [13,14]. The key point is that it is redundant, shift invariant, linear, and it gives a better approximation to the continuous wavelet transform than the approximation provided by the orthonormal discrete wavelet transform. Unlike the discrete wavelet transform, the undecimated discrete wavelet transform does not incorporate the down sampling operations. Thus, the approximation coefficients and detailed coefficients at each level are the same length as the original signal.

Figure 1 shows the flowchart of our proposed method. The main steps are outlined below:

1. Apply undecimated discrete wavelet transform to the noisy image up to level 2 to produce the noisy wavelet coefficients.
2. Compute the hierarchical correlations of the detailed coefficients between level 1 and level 2 for three different (horizontal, vertical and diagonal) directions.
3. Select appropriate threshold values based on the obtained hierarchical correlation values.
4. Apply the selected threshold values to the coefficients of level 1 to remove the noise, and obtain the modified detailed coefficients for level 1.
5. Apply inverse wavelet transform to the modified wavelet coefficients to obtain a denoised image.
6. Repeat steps 1-5 again, leading to obtain a final denoised image.

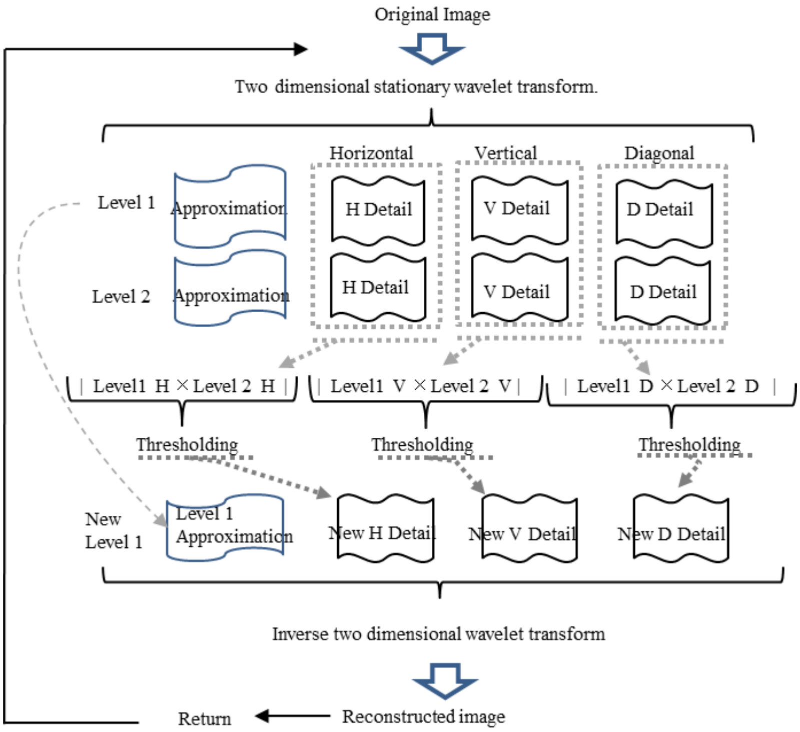


Fig. 1. Flow chart of the proposed method.

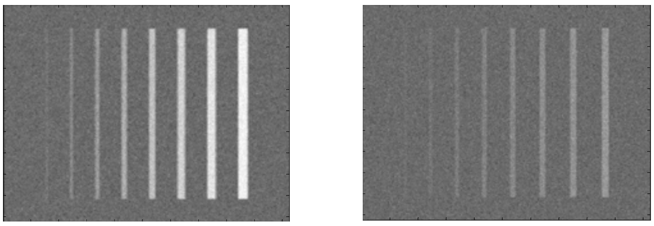


Fig. 2. Computer-simulated images with higher contrast with low noise level (left) and lower contrast with higher level of noise (right).

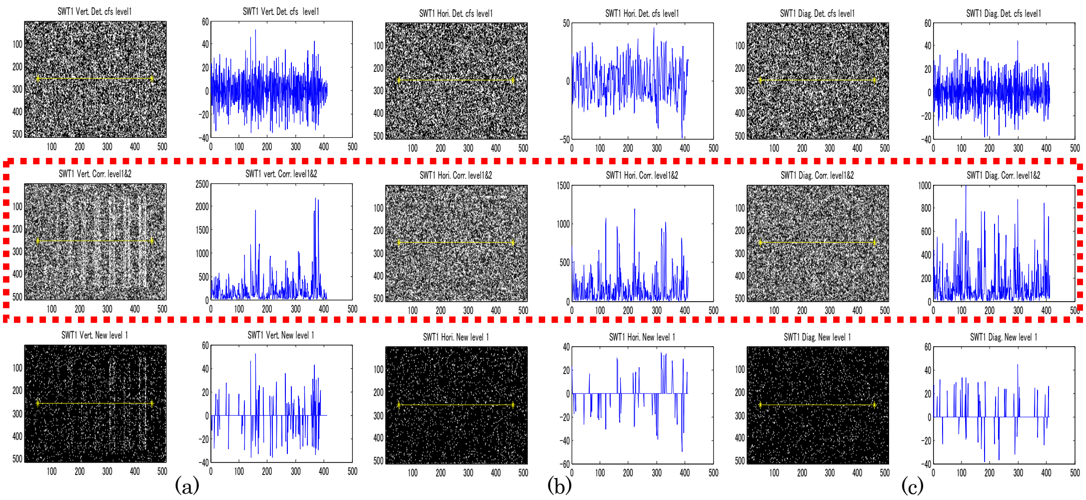


Fig. 3 . An example showing images and plots of the three detailed coefficients, (a) vertical, (b) horizontal, and (c) diagonal directions. Detailed coefficients at level 1 (top row), correlation values between level 1 and level 2 (middle row), and modified detailed coefficients after noise denoising (bottom row).

A simulation was designed and its framework is as follows. A simulation image $g(x,y)$ was given by a spatial convolution between a uniform-distributed signal (an object) $f(x,y)$ having intrinsic noise $u(x,y)$ and a blurring function function B. If the external noise $v(x,y)$ was also taken into consideration, the resulting image could be represented by the following formula:

$$g(x,y) = \sum_{s=1}^{8} \{[s \times f(x,y) + u(x,y) \times W] * B + v(x,y) \times K\}, \qquad (1)$$

where the symbol * represents the convolution operation, and s is an integer representing the number of strips of the simulated image. The terms of W and K are weighting coefficients used to adjust noise level.

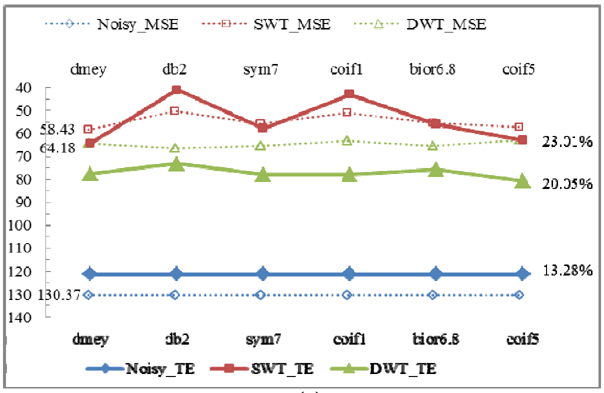
In the simulation studies, the input image $f(x,y)$ consisted of 8 stripes with different width, representing structural fibers on mammograms. The $u(x,y)$ and $v(x,y)$ were Poission noise and Gaussian noise, respectively. We used a “$m \times m$” (m is an odd integer) 8-neighbothood averaging filter as the blurring function. The extent of blurring was adjusted by varying the filter size. Figure 2 shows two simulated images with different resolution, contrast and noise level.

We used six different wavelet basis functions, namely, dmey, db2, sym7, coif1, bior6.8, and coif5, to perform wavelet transform of the simulated images by use of our proposed method. In this work, we employed mutual information as a metric of image quality [15,16] for selecting the optimal wavelet basis function to be used in denoising mammographic images. We also used metrics of the mean square error (MSE) and signal-to-noise ratio (SNR) for confirmation.

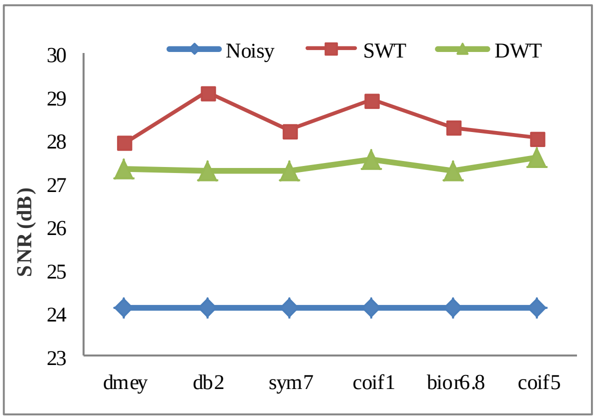
In addition to the simulation studies, a total of 30 mammograms taken from 30 different patients (14 normal cases and 16 abnormal cases) were also used for investigation of the effectiveness of the proposed method. Moreover, the validity of the proposed method was verified by perceptual evaluation.

3. RESULTS AND DISCUSSION

Figure 3 shows an example of processing the simulated images by use of the proposed method. The vertical, horizontal and diagonal wavelet coefficients are shown in Figs. 3(a)-3(c), respectively. The wavelet basis function used in this example was Coiflets wavelet with order 1 (coif1). The top row of Fig. 3 shows the wavelet coefficients of subbands (left column) and coefficient distribution (right column) at level 1. The middle row of the figure depicts the correlation values between level 1 and level 2 (left column) and the distribution of the correlation. The bottom row of the figure shows the modified coefficients of subbands (left column) and coefficient distribution (right column) at level 1 after performing first run of processing of the proposed method. Looking at the initial coefficient distribution of level 1 (top row, left column) and the modified coefficient distribution (bottom row, right column), it is obvious that the noise has been substantially removed.



(a)

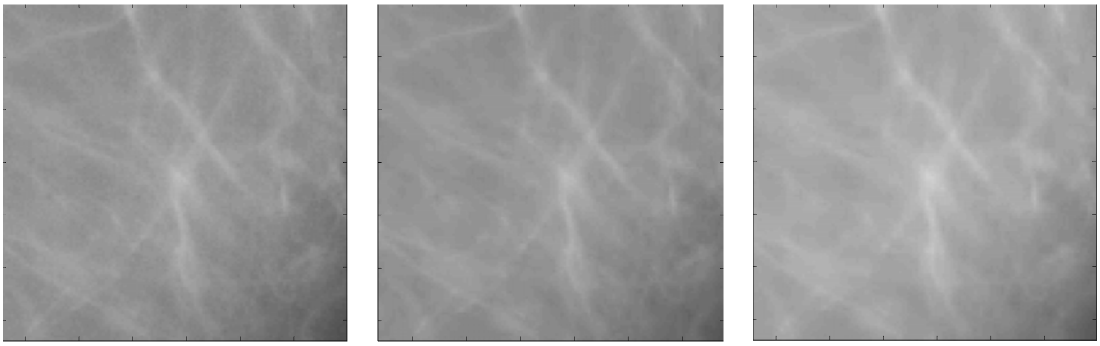


(b)

Fig. 4. (a) The MSE and transmitted efficiency (%), and (b) SNR are shown with respect to basis functions used in wavelet transform for the simulated images (Noisy), images processed by the proposed method (SWT) and that by the conventional discrete wavelet transform method (DWT).

Shown in Fig. 4(a) is the MSE values for the simulated images (Noisy), images processed by the proposed method (SWT) and that by the conventional discrete wavelet transform method (DWT), with respect to 6 different basis functions used in wavelet transforms. In this study, “transmitted efficiency” (TE) was used and defined as the ratio between mutual information and the input entropy. The TE may also be used as a relative measure for indicating how good the image quality of an image is. It is noted from Fig. 4(a) that both the MSE and TE show the same tendency with respect to the superiority rankings for the 6 wavelet basis functions. Among the 6 basis functions, Daubechies wavelet with order 2 (db2) gave the best result. Figure 4(b) demonstrates the performance of the SNR obtained from the 6 basis functions with various methods. As shown in the figure, db2 provided the best results. The result was consistent with that shown in Fig. 4(a).

The 30 clinical mammograms were processed by use of the proposed method. Figure 5 illustrates an example of the processed results. The db2 wavelet basis function was used in this example. Perceptual evaluation results showed that the proposed method is superior to the conventional method.



(a) (b) (c)

Fig. 5. Comparison of processing results of mammogram to the original image. (a) Original image, (b) image obtained with the proposed method, and (c) image obtained with the conventional method.

4. CONCLUSIONS

We proposed and evaluated an approach to improving image quality of digital mammographic images by use of undecimated discrete wavelet transform. The features of the proposed technique included iterative use of undecimated multi-directional wavelet transforms at adjacent scales. Experimental results indicate that our proposed method has the potential to effectively reduce noise while maintaining high-frequency information of original images.

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