AN IMAGE ENHANCEMENT ALGORITHM BASED ON A CONTRAST MEASURE IN THE WAVELET DOMAIN FOR SCREENING MAMMOGRAMS

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ABSTRACT

Currently, radiologists mainly use their eyes to discern cancer when they screen the mammograms. However, in many cases, cancer is not easily detected by the eyes because of bad imaging conditions. In order to improve the diagnostic rate of cancer, image enhancement technology is often used to enhance the image and aid the radiologists. In this paper, we developed a new image enhancement technology in the wavelet domain for radiologists to screen mammograms. The new image enhancement algorithm has several advantages. First, the image enhancement is based on a contrast measure defined in the wavelet domain which matches the human vision system better. The enhanced images are therefore more suitable for the human eye; second, the image enhancement is carried on in the wavelet domain which saves time if the image is compressed by JPEG2000. The algorithm was tested by an expert and the results are progressive.

Index Terms—Image enhancement, breast cancer diagnosis, wavelet, contrast measure, mammograms, ROC analysis.

1. INTRODUCTION

Cancer is the second leading cause of death for both men and women in the United States and is expected to become the leading cause of death in the next several decades. Therefore, how to detect, analyze and treat cancers has become a big research field. Modern imaging technology has already had lifesaving effects on the ability to detect cancer early and more accurately diagnose the disease. However, in order to further improve the efficiency and veracity of diagnoses and treatment, image processing technology has been widely applied to analysis and recognition of cancer, evaluation of the treatment effectiveness, and prediction of the development of cancer.

In this paper, we will investigate image enhancement technology for aiding the radiologists in screening mammograms. A mammogram is a picture of the breast taken with a safe, low dose X-ray machine. It is a recommended exam for women in early detection of breast cancer in the USA and many other countries. One big issue that arises when the radiologist screens mammograms is that the contrast of the images obtained with low dose X-ray machine is low. In the low contrast images, the minor difference between the normal tissue and the malignant disease is not discernable and makes the interpolation very difficult. Thus, how to enhance the contrast of the images becomes very important when the mammograms are screened.

In the past, several image enhancement technologies have been proposed for screening mammograms. In [1], a combined approach with fuzzy logic and structure tensor is proposed for improved enhancement of possible micro-calcifications in digital mammograms. This method can suppress non-MCs regions while enhancing the MC's regions. In [2], a multi-scale analysis method is proposed for the feature enhancement. The described method can make unseen or barely seen features of mammography more obvious without requiring additional radiation. In [3], a method aimed at minimizing image noise while optimizing contrast of image features is also presented. This method is based on local modification of multi-scale gradient magnitude values provided by the redundant dyadic wavelet transform. In [4], an algorithm for feature enhancement in mammograms is presented, using discrete wavelet decompositions which are called integrated wavelets. The integrated wavelets are optimally designed for enhancement of multi-scale structures in images. This method is especially effective for the enhancement of micro-calcifications. Besides the work mentioned above, other image enhancement technologies for screening mammograms include [5][6][7][8].

In this paper, we propose a new image enhancement technology which is based on a multi-scale contrast measure in the wavelet domain for radiologists to screen the mammograms. Our image enhancement technology is a direct contrast enhancement technology because it modifies the contrast of the image directly [9][10]. The advantages of the proposed image enhancement technology lie in: (1) Ease of adjustment by end-users(for example, adjusting a single parameter); (2) the image enhancement technology can be applied to JPEG2000 compressed images in the decompression stage to reduce the time for image enhancement which modifies the wavelet coefficients obtained in the decompression stage; (3) The proposed image enhancement technology modifies a multi-scale measure which matches the human vision system resulting in the enhanced images having better visual quality.

2. A MULTISCALE CONTRAST MEASURE DEFINED IN THE WAVELET DOMAIN

A key step in the direct image enhancement approach is the establishment of a suitable image contrast measure [9][10]. For simple patterns, two definitions of contrast measure, (the *Michelson contrast measure* and the *Weber contrast measure*), have been defined. However, neither is suitable for measuring the contrast in complex images. For complex images, a number of contrast measures were proposed [8][11-13] and have been used for direct image enhancement. However, all of the contrast measures do not consider the human contrast sensitivity. Because human contrast sensitivity is a function of spatial frequency, an image's spatial frequency content should be considered in the definition of contrast. The contrast measure proposed in [14] explicitly satisfies this requirement. The definition of local bandlimited contrast assigns a contrast value to every point in the image for each spatial frequency band. For each frequency band, contrast is defined as the ratio of the bandpass-filtered image at that frequency to which the image lowpass-filtered to an octave below the same frequency. This multi-scale contrast structure has found wide applications, especially in image processing problems, related to the human vision system [9], [10]. This paper extends Eli Peli's definition of contrast measure to wavelet domain and uses it to develop a new image enhancement algorithm. In order to extend Eli Peli's definition of contrast measure to wavelet domain, we need to describe the multi-scale representation of an image.

Let $A_0(i,j)$ be a two dimensional image, $\{h_n\}$, $\{g_n\}$ be wavelet analysis filters and $\{\hat{h}_n\}$ $\{\hat{g}_n\}$ be appropriate wavelet synthesis filters, then the K-level wavelet transform

$$\{A_N(i,j), D_N^1(i,j), D_N^2(i,j), D_N^3(i,j)\}_{N=1}^{K}$$

of $A_0(i,j)$ can be described as [15]:

$$A_N(i,j) = \sum_{m,n\in Z} h(m)h(n)A_{N-1}(2i-m, 2j-n) \qquad (1)$$

$$D_N^1(i,j) = \sum_{m,n\in Z} h(m)g(n)A_{N-1}(2i-m, 2j-n) \qquad (2)$$

$$D_N^2(i,j) = \sum_{m,n\in Z} g(m)h(n)A_{N-1}(2i-m, 2j-n) \qquad (3)$$

$$D_N^3(i,j) = \sum_{m,n\in Z} g(m)g(n)A_{N-1}(2i-m, 2j-n) \qquad (4)$$

where $A_N(i,j)$ represents the low-frequency of $A_{N-1}(i,j)$ and $D_N^1(i,j)$ represents the horizontal low-frequency and vertical high frequency of $A_{N-1}(i,j)$. $D_N^2(i,j)$ represents the vertical low-frequency and horizontal high frequency of $A_{N-1}(i,j)$, $D_N^3(i,j)$ represents the vertical high-frequency and horizontal high frequency of $A_{N-1}(i,j)$. The wavelet transform has reconstruction algorithm which can be expressed as

$$\begin{aligned} A_{N-1}(i,j) = 4\times[&\sum_{m,n\in Z} \hat{h}(m)\hat{h}(n)A_N(\frac{i-m}{2},\frac{j-n}{2}) \\ &+ \sum_{m,n\in Z} \hat{h}(m)\hat{g}(n)D_N^1(\frac{i-m}{2},\frac{j-n}{2}) \\ &+ \sum_{m,n\in Z} \hat{g}(m)\hat{h}(n)D_N^2(\frac{i-m}{2},\frac{j-n}{2}) \\ &+ \sum_{m,n\in Z} \hat{g}(m)\hat{g}(n)D_N^3(\frac{i-m}{2},\frac{j-n}{2}) \end{aligned} \qquad (5)$$

The definition of the contrast measure is similar to the contrast measure in [14], it also has a multi-scale structure. The multi-scale local contrast measure in the wavelet domain is defined as

$$c_N^k(i,j) = \frac{D_N^k(i,j)}{A_N(i,j)} \quad (k=1,2,3) \qquad (6)$$

3. AN IMAGE ENHANCEMENT ALGORITHM USING THE MULTISCALE CONTRAST MEASURE FOR SCREEING MAMOGRAMS

Let the original image $A_0(i,j)$ be decomposed into K-levels subbands, then the obtained subband components are $\{A_K(i,j), D_K^1(i,j), D_K^2(i,j), D_K^3(i,j)\}$,…,$\{A_1(i,j), D_1^1(i,j), D_1^2(i,j), D_1^3(i,j)\}$.

Let the contrast of the original image be $C = \{c_N^k(i,j)\}$, the contrast of the enhanced image be $\overline{C} = \{\overline{c}_N^k(i,j)\}$, and if contrast manipulation factors are

$\pi = \{\lambda_N^k(i,j)\}$, then the relationship between them can be described by

$$\overline{c}_N^k(i,j) = \lambda_N^k(i,j) c_N^k(i,j) \quad (7)$$

Let's introduce how to obtain the image with contrast $\overline{C} = \{\overline{c}_N^k(i,j)\}$ from the original image with contrast $C = \{c_N^k(i,j)\}$. If we start with the K-th subband components $A_K(i,j), D_K^1(i,j), D_K^2(i,j), D_K^3(i,j)$

From(7) we have

$$\begin{aligned} \frac{\overline{D}_K^k(i,j)}{\overline{A}_K(i,j)} &= \overline{c}_K^k(i,j) = \lambda_K^k(i,j) c_K^k(i,j)) \\ &= \lambda_K^k(i,j) \frac{D_K^k(i,j)}{A_K(i,j)} \end{aligned} \quad (8)$$

Let

$$\overline{A}_K(i,j) = A_K(i,j)$$
$$\overline{D}_K^1(i,j) = \lambda_K^1(i,j) D_K^1(i,j)$$
$$\overline{D}_K^2(i,j) = \lambda_K^2(i,j) D_K^{21}(i,j)$$
$$\overline{D}_K^3(i,j) = \lambda_K^3(i,j) D_K^3(i,j)$$

Obviously, (6) is satisfied.

Now let's consider how to obtain $\overline{A}_{K-1}(i,j)$, $\overline{D}_{K-1}^1(i,j)$, $\overline{D}_{K-1}^2(i,j), \overline{D}_{K-1}^3(i,j)$. Similar to (8), we also have

$$\begin{aligned} \frac{\overline{D}_{K-1}^k(i,j)}{\overline{A}_{K-1}(i,j)} &= \overline{c}_{K-1}^k(i,j) = \lambda_{K-1}^k(i,j) c_{K-1}^k(i,j) \\ &= \lambda_{K-1}^k(i,j) \frac{D_{K-1}^k(i,j)}{A_{K-1}(i,j)} \end{aligned} \quad (9)$$

(9) can be changed to be

$$\overline{D}_{K-1}^k(i,j) = \lambda_{K-1}^k(i,j) \frac{D_{K-1}^k(i,j)}{A_{K-1}(i,j)} \overline{A}_{K-1}(i,j) \quad (10)$$

where $\overline{A}_{K-1}(i,j)$ can be obtained by

$$\begin{aligned} \overline{A}_{K-1}(i,j) = 4 \times [&\sum_{m,n \in Z} \hat{h}(m)\hat{h}(n)\overline{A}_K(\frac{i-m}{2}, \frac{j-n}{2}) \\ &+ \sum_{m,n \in Z} \hat{h}(m)\hat{g}(n)\overline{D}_K^1(\frac{i-m}{2}, \frac{j-n}{2}) \\ &+ \sum_{m,n \in Z} \hat{g}(m)\hat{h}(n)\overline{D}_K^2(\frac{i-m}{2}, \frac{j-n}{2}) \\ &+ \sum_{m,n \in Z} \hat{g}(m)\hat{g}(n)\overline{D}_K^3(\frac{i-m}{2}, \frac{j-n}{2})] \end{aligned} \quad (11)$$

Using the similar processing, we can obtain other enhanced subband components. After we get $\overline{A}_1(i,j), \overline{D}_1^1(i,j)$, $\overline{D}_1^2(i,j), \overline{D}_1^3(i,j)$, we can obtain the enhanced image $\overline{A}_0(i,j)$ using the similar processing.

4. EXPERIMENTAL RESULTS

In order to measure the performance of the proposed contrast based image enhancement algorithm, mammograms were selected from the mammography database at the University of South Florida for human subject tests. The human subject in this experiment is an expert who has experience in recognizing the mass or calcification regions in mammograms. This expert, however, is not a radiologist. Two groups of images were used in the experiments. Each group was composed of 20 cancerous images and 20 non-cancerous images. For each cancerous image, either calcification regions or mass regions were included. For each non-cancerous image, regions such as calcification region, mass regions, or architecture distortion were not included. Thus, an expert can determine whether an image is a cancerous image by determining whether it includes calcification regions or mass regions. One group was used for testing without image enhancement; the other group was used for testing with image enhancement. In the experiments with image enhancement, the level for wavelet transform is four and the wavelet used was 16-tap orthogonal wavelet. For easy control, the contrast manipulation factors were the same, ($\lambda_N^k(i,j) = \lambda$). The test procedure is similar to the procedure used in [16]: in the group tested without image enhancement, the expert made a decision using the original images. In the group tested with image enhancement, the expert selected an ROI in the images and the proposed image enhancement was used to enhance the region selected [16]. For image enhancement, the expert can adjust the factor λ so that the visual quality of the enhanced image satisfies his needs. After the image was enhanced, the expert marked the lesion found and chose the level of confidence for the lesion where cancer was presented. The scale ranged from 1 to 5 (1 meaning definitely negative (total confidence that there are no malignant lesions), and 5 meaning definitely positive (total confidence that there is a malignant lesion)[16][17]. The un-located lesions which were truly positive, were classified as definitely negative.

After the data were collected, ROC analysis was applied to compare the two diagnostic systems (one with enhancement and the other without enhancement). The ROC analysis tool provided in [17] was used in our experiments. The area under the ROC curve was used to quantify the performance of each diagnostic system. Figure 1 shows the ROC curves for two diagnostic systems and clearly indicates that the diagnostic systems with image enhancement (area under Curve is 0.94) is better than the diagnostic systems without image enhancement (area under Curve is 0.83). Figure 2 shows a sample of a selected region before and after enhancement. From the images, we can also see that the enhanced region has higher contrast than the un-enhanced region.

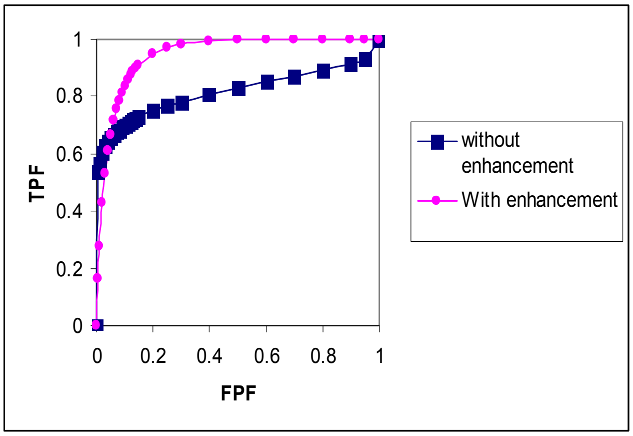
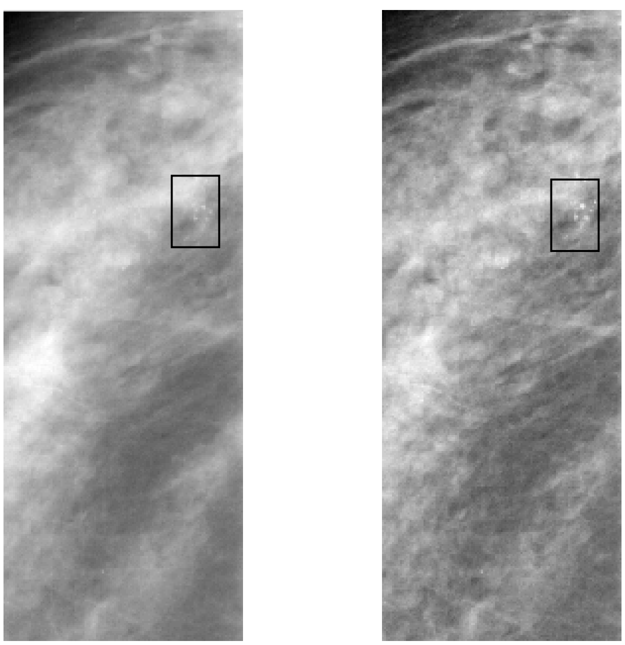


FIG 1. ROC CURVES



(a) Original region (b) After Enhancement

FIG 2. Sample of regions before and after enhancement; The rectangle region is the calcification region.

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