Fuzzy Logic Approach to Breast Ultrasound Image Enhancement

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Abstract

Breast cancer is still a serious disease in the world. Early detection is essential for prevention and diagnosis. Breast ultrasound image has been a valuable adjunct to mammography in the detection and classification of breast lesions. However, the fuzzy nature of the ultrasound images and the low contrast between the breast lesions and surrounding tissues make them difficult to provide accurate and effective information for diagnosis.

This paper presents a novel enhancement algorithm based on fuzzy logic with the ability to enhance the fine details of the ROIs (region of interests) of the ultrasound images, while avoiding overenhancement.

First, we normalize the images and then fuzzify the normalized images based on the maximum entropy principle. Edge and textural information is extracted and applied to describe the lesions' features, then the contrast radio measuring the degree of enhancement is computed and modified by using both the global and local information. Finally, the defuzzification is used to obtain the enhanced ultrasound images.

To demonstrate the performance of the proposed approach, the algorithm is tested on a variety of ultrasound images. Experimental results confirm that the proposed method has better performance in enhancing breast ultrasound images without overenhancement and underenhancement. It can enhance the fine details of the breast lesions effectively that will be useful for further processing.

Keywords: Enhancement, Fuzzy logic, Texture analysis, Maximum entropy principle, Breast ultrasound image.

1. INTRODUCTION

Breast cancer is still one of the most common cancers among women in the world. Because the causes of this disease still remain unknown, early detection is very important and critical for breast cancer control. The treatment for the early detected disease will be more effectively treated to reduce the mortality and the cost.

Mammograph has limitation in detecting breasr cancer in dense breast tissue of young patients. The breast ultrasound imaging has proven to be a valuable adjunct to mammography in the detection and classification of breast lesions [1]. The results in [2] suggest that the denser the breast parenchyma the higher the accuracy in detecting malignant tumours using ultrasound imaging. Breast ultrasound examination has played more and more significant role in detecting breast cancer.

However, the fuzzy nature of the ultrasound images and the low contrast between the lesions and surrounding tissues makes the radiologists difficult to provide accurate and effective diagnosis. Many image enhancement methods and algorithms [3,4] have been employed to handle ultrasound images.

In this paper, we propose a novel contrast enhancement algorithm based on fuzzy logic and textural homogeneity. The maximum fuzzy entropy principle is used to fuzzify the original image, then edge and textural information is extracted to evaluate the lesions' features, and local information is employed to define the enhancement criterion. We will enhance the image according to this criterion.

2. PROPOSED APPROACH

The proposed method consists of five steps: image normalization, image fuzzification, edge information extraction, textural information extraction, and contrast enhancement.

2.1. Normalization

Breast ultrasound images may vary largely in gray levels, and the ranges of the intensities of some images could be very narrow. Normalization is a necessary step for pre-processing.

$$g(i,j) = g_{\min} + \frac{(g_{\max} - g_{\min}) \times (g_o(i,j) - g_{o\min})}{(g_{o\max} - g_{o\min})} \quad (1)$$

where $g_{o\min}$ and $g_{o\max}$ are the minimum and maximum intensity levels of the original image, $g_{\min}$ and $g_{\max}$ are the minimum and maximum intensity levels of the normalized image, and $g_o(i,j)$ and $g(i,j)$ are the gray levels at the coordinates (i,j) before and after normalization, respectively.

2.2. Fuzzification

2.2.1. Membership function selection

The membership function of a fuzzy set maps all the elements of a set into real numbers $\in [0, 1]$. The most commonly used membership function for a gray level image is the standard S function, which can be computed as follows [5]:

$$S(g;x,y,z)=\begin{cases}0 & g\le x\\ \dfrac{(g-x)^2}{(y-x)(z-x)} & x\le g\le y\\ 1-\dfrac{(g-z)^2}{(z-y)(z-x)} & y\le g\le z\\ 1 & g\ge z\end{cases} \tag{2}$$

The values of the function represent the brightness degrees of the pixels in terms of intensities.

2.2.2. Parameters of membership

In Eq. (2), the selection of the middle point y could be viewed as an object-background classification problem, and the techniques based on entropy can be applied [5].

The entropies less or greater than the threshold t are computed, then the middle point can be computed as below:

$$t^* = Arg\max_{t=0}^{N}\left\{H_l(t)+H_g(t)\right\} \tag{3}$$

where t^* is the optimal threshold, t is the level of gray intensity, and N is the maximum intensity of the image. $H_l(t)$ represents the entropy of the pixels whose intensities are less than t and $H_g(t)$ stands for the entropy of the pixels whose intensities are greater than or equal to t.

The value of t^* is used as the middle point of the S function. The image will be fuzzified by using S function.

$$\mu(i,j)=S(g(i,j);x,y,z) \tag{4}$$

where g(i,j) is the intensity at the coordinates (i,j), $y=t^*$, x and z are the abscissas corresponding to the first peak and last peak of the histogram, respectively.

2.3. Edge information extraction

Among the early indicators of breast cancers, the mass shape and margin, and the membrane smoothness are the primary features. The edge operator is applied.

$$e_\mu(i,j)=\frac{abs(\delta_\mu(i,j))}{\delta_{\mu\max}} \tag{5}$$

where $\delta_\mu(i,j)$ is the edge value of the fuzzified image computed by using Sobel operator, and $\delta_{\mu\max}$ is the maximum edge value.

2.4. Texture information extraction

In this paper, Laws' texture energy measures (TEM) are used to determine ROI textural properties. The measures are derived from the following five vectors:

$L5=(1,4,6,4,1)$ $E5=(-1,-2,0,2,1)$

$S5=(-1,0,2,0,-1)$ $R5=(1,-4,6,-4,1)$

$W5=(-1,2,0,-2,-1)$.

The texture value of pixel (i,j), $f_\mu(i,j)$, is computed:

$$f_\mu(i,j)=\frac{abs(f_{\mu L5^T\times E5}(i,j))}{f_{\mu L5^T\times E5\max}}\times\frac{abs(f_{\mu L5^T\times S5}(i,j))}{f_{\mu L5^T\times S5\max}} \times\frac{abs(f_{\mu E5^T\times L5}(i,j))}{f_{\mu E5^T\times L5\max}}\times\frac{abs(f_{\mu S5^T\times L5}(i,j))}{f_{\mu S5^T\times L5\max}} \tag{6}$$

where $f_{\mu L5^T\times E5}(i,j)$, $f_{\mu L5^T\times S5}(i,j)$, $f_{\mu L5^T\times R5}(i,j)$ and $f_{\mu L5^T\times W5}(i,j)$ are the convoluted results of the $\mu(i,j)$ with the four masks, and $f_{L5^T\times E5\max}$, $f_{L5^T\times S5\max}$, $f_{L5^T\times R5\max}$ and $f_{L5^T\times W5\max}$ are the corresponding maximum values, respectively.

2.5. Contrast Enhancement

2.5.1. Compute the contrast

The contrast is defined as following:

$$C_\mu(i,j)=\frac{\left|\mu(i,j)-\overline{\mu}_w(i,j)\right|}{\left|\mu(i,j)+\overline{\mu}_w(i,j)\right|} \tag{7}$$

$$\overline{\mu}_w(i,j)=\frac{\sum_{m=i-(w-1)/2}^{i+(w-1)/2}\sum_{n=j-(w-1)/2}^{j+(w-1)/2}(\mu(m,n)\times f_\mu(m,n)\times e_\mu(m,n))}{\sum_{m=i-(w-1)/2}^{i+(w-1)/2}\sum_{n=j-(w-1)/2}^{j+(w-1)/2} f_\mu(m,n)\times e_\mu(m,n)} \tag{8}$$

where $\overline{\mu}_w(i,j)$ is the local mean of the window whose size is $w\times w$ and centered at the location (i,j).

2.5.2. Modify the contrast ratio

An exponential function $k(i,j)$ is designed to transform C_μ into C'_μ, which specially boosts perceptibility of regions with low contrast while not affecting high-contrast regions. $k(i,j)$ is determined according to the nature of the original image and the local information.

$$C'_\mu(i,j) = \left(C_\mu(i,j)\right)^{k(i,j)} \tag{9}$$

where $k(i,j)$ is the contrast amplification constant at location (i,j). It significantly affects the degree of the contrast enhancement.

2.5.3. Determine the amplification exponent

Firstly, the fuzzy entropy, $En(i,j)$, is defined and used to evaluate the uniformity degree of the local region [6]. Secondly, the local contrast of the original image is computed, and then some measurements of the contrast are calculated and used to evaluate the degree of contrast of the original image. The minimal and maximal amplification constants, $k_{\min}$ and $k_{\max}$, are determined based on the contrast of the original image. Finally, the value of local contrast amplification constant, $k(i,j)$, is calculated according to fuzzy entropy.

$$k(i,j) = k_{\min} + \frac{(En(i,j) - En_{\min}) \times (k_{\max} - k_{\min})}{En_{\max} - En_{\min}} \tag{10}$$

where $k_{\min}$ are $k_{\max}$ the minimal and maximal local contrast amplification constant, respectively. $En_{\min}$ are $En_{\max}$ the minimal and maximal local fuzzy entropy, respectively.

2.5.4. Defuzzification

The enhanced intensity of pixel (i,j) can be obtained by using the inverse function $S^{-1}(\mu'(i,j);x,y,z)$.

$$g'(i,j) = S^{-1}(\mu'(i,j);x,y,z)$$
$$= \begin{cases} g_{\min} + \dfrac{g_{\max} - g_{\min}}{z-x} \times \sqrt{\mu'(i,j) \times (y-x)(z-x)} & 0 \le \mu'(i,j) \le \dfrac{(y-x)}{(z-x)} \\ g_{\min} + \dfrac{g_{\max} - g_{\min}}{z-x} \times (z - x - \sqrt{(1-\mu'(i,j)) \times (z-y)(z-x)} & \dfrac{(y-x)}{(z-x)} < \mu'(i,j) \le 1 \end{cases} \tag{11}$$

where $g_{\min}$ and $g_{\max}$ are the minimum gray level and maximum gray level after the enhancement, respectively.

3. EXPERIMENTAL RESULTS

To test the performance of the proposed algorithm, many breast ultrasound images were used, and the enhanced results were compared with the original images. The breast ultrasound images used in the experiments were acquired from the Digital Database for Breast Sonography (DDBS), which was built by Harbin Institute of Technology and the Second Affiliated Hospital of Harbin Medical University. In the experiments, the test images were collected by using a VIVID 7 (GE, USA) with a 5-14 MHz linear probe, and captured directly from the video signals. The cases from DDBS consisted of 86 images of 49 cases, and each single lesion is in one image. Of the 49 cases, 14 were benign solid lesions (30 images), and 35 were malignant solid lesions (56 images). All lesions were confirmed by biopsy or operation, and the ROIs were outlined by a radiologist according to the biopsy results.

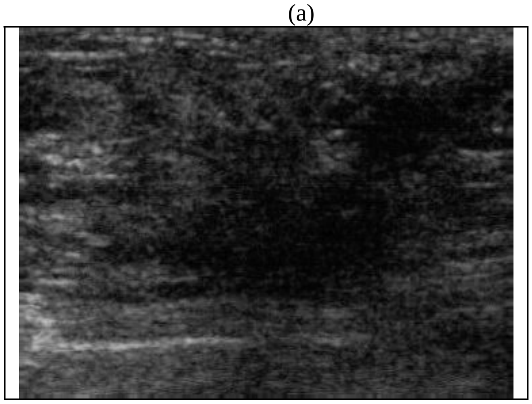
First, the regions of interest (ROIs) were selected. For each image, a ROI contains at least one lesion. Here, due to the page limitation, we just present two samples to demonstrate the performance of the proposed method.

Fig. 1(a) and 2(a) are the original images, and Fig. 1(b) and 2(b) are the results obtained by using the proposed method.

After enhancement by using the proposed method, the lesions' features are significantly enhanced. Fig. 1(a) has a compact mass at the center of the image, and the mass echo is very low. It is very dark, and is difficult to be distinguished from the background. In Fig. 1(b), the mass become clearer and easier to detect, and the shape and edge can be better distinguished. In Fig. 2(a) the images of the tissues inside the mass are blur and invisible. After enhancement, they become more distinct. The edge of mass is clearer and can be distinguished easily, while the boundary on the upper portion of the image is not overenhanced.

The experiments have shown that the proposed approach can enhance the contours and the fine details significantly. The enhanced images can be processed further to detect the masses and microcalcifications with high accuracy. Radiologists have applied the algorithm to breast cancer diagnosis and discussed the result using Receiver Operating Characteristic (ROC) curve. The results indicated that the value of A_z without contrast enhancement was 0.87 comparing to 0.899 with contrast enhancement using the proposed approach [7].

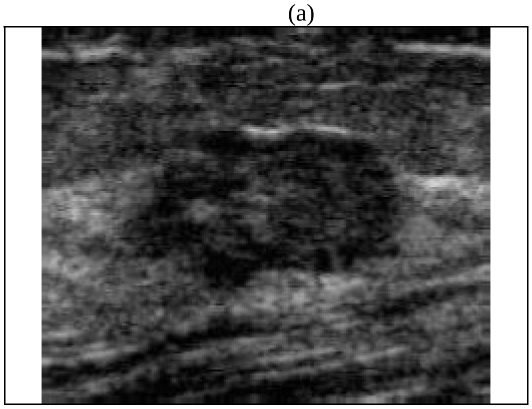
(a)



(b)

Fig. 1. (a) The original image (b) The image enhanced by the proposed method.

(a)



(b)

Fig. 2. (a) The original image (b) The image enhanced by the proposed method.

4. CONCLUSIONS

A breast ultrasound image enhancement algorithm based on fuzzy logic and textural homogeneity is studied. From the experiments, the algorithm shows two advantages: the details of ROIs are much clearer and with no overenhancement. The good performance is due to the factors: (1) The S function is used for fuzzification and the parameters are determined using the maximum entropy principle. Therefore, during the fuzzification, it will have the maximum information. (2) The edge and texture information are extracted firstly in fuzzy domain. The enhancement parameters are determined based on the edge and texture information. Hence, the edges and textures will be enhanced while the background is not enhanced or even deenhanced. The proposed approach will be useful for computer-aided diagnosis systems.

5. References

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