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Speckle reduction approach for breast ultrasound image and its application to breast cancer diagnosis

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A B S T R A C T

Objectives: To retrospectively evaluate the effects of a speckle reduction algorithm on radiologists' diagnosis of malignant and benign breast lesions on ultrasound (US) images.

Methods: Using a database of 603 breast (US) images of 211 cases (109 benign lesions and 102 malignant ones), the original and speckle-reduced images were assessed by five radiologists and final assessment categories were assigned to indicate the probability of malignancy according to BI-RADS-US. The diagnostic sensitivity and specificity were investigated by the areas (Az) under the receiver operating characteristic (ROC) curves.

Results: The sensitivity and specificity of breast lesions on Ultrasound images improved from 88.7% to 94.3%, from 68.6% to 75.2%, respectively, and the area (Az) under ROC curve of diagnosis also increased from 0.843 to 0.939, $Z = 4.969$, there were significant differences in the Az between the original breast lesions and speckle-reduced ones on Ultrasound images ($P < 0.001$). The diagnostic accuracy of breast lesions had been highly improved from 78.67% to 92.73% after employing this algorithm.

Conclusions: The results demonstrate the promising performance of the proposed speckle reduction algorithm in distinguishing malignant from benign breast lesions which will be useful for breast cancer diagnosis.

1. Introduction

Breast cancer is one of the most common cancers and a major cause of death among women in the world [1,2]. Finding an accurate and effective diagnostic method is very important and critical for breast cancer diagnosis. Early detection and diagnosis are very essential in reducing the mortality, and, improving the clinical curative rate and life quality of the patients.

Ultrasonography has been a preferred method due to its quick imaging and high reproducibility for breast cancer detection. In addition, it is low cost, portable, no radiation and easily accepted by the patients. However, the US images have some artifacts. When the range of the intensities on US image was narrow, the edges of the breast textures and masses were obscure, the contrast was low, and the masses usually cannot be discovered [3,4]. Many researchers try to improve the quality of the ultrasound images. The American College of Radiology Imaging Network (ACRIN) also takes multi-center trials to determine who may benefit from supplemental US screening [5–7].

It is well known that breast ultrasound (BUS) images suffer from speckle due to the interference of back-scattered signal, and the speckle noise is the limiting factor for image contrast in all US images and produces the familiar apparently random modulation of the image in regions that would otherwise be displayed as a uniform gray level [8], so the speckle significantly degrades the image quality and hinders the discrimination of the fine details.

Several filters were proposed for reducing speckle noise: linear filters [9–11], temporal averaging [12], median filter [13], and Wiener filter. However, these filter methods were developed mainly for additive random noise reduction, and had little success in speckle suppression. Nonlinear diffusion method [14–17] can be regarded as an adaptive filter, whose diffusion (smoothing) direction and strength are controlled by an edge detection function. A speckle reducing anisotropic diffusion (SRAD) [15] exploited a coefficient of the variation as an edge detector for speckled imagery. However, SRAD is only for uncompressed echo envelope images, and its performance will decline when it is directly applied to log-compressed images. In addition, the speckle detector which simply combines the gradient magnitude and Laplacian may not perform well for the boundaries between regions with different gray levels. A nonlinear coherent diffusion (NCD) model [14] combines three different models (isotropic diffusion, anisotropic coherent diffusion and mean curvature motion). This produces non-speckle regions by

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low-pass filtering, and substantially preserving information associated with the resolved-object structures. However, in NCD model, a nonselective Gaussian smoothing filter is needed before estimating structure tensors, which may eliminate feature details smaller than the smoothing kernel. Generally, the nonlinear diffusion technique relies on the gradient operator which cannot separate signal and noise precisely.

In order to overcome these disadvantages of the above filters, we have developed an ultrasound image speckle reduction algorithm based on two-dimensional textural homogeneity histogram and directional average filters. All the parameters for describing speckle noise and terminating the iterative process are derived automatically based on the characteristics of the given US images. The proposed approach can remove the speckle noise and preserve the edges and details of the US images at the same time. The aim of this study is to validate the effectiveness and usefulness of this algorithm that can improve the diagnostic accuracy.

2. Materials and methods

2.1. Data set

All patients (female, mean age ± SD, 46.7 ± 11.05 years; range, 18–74 years) of the second affiliated hospital of Harbin Medical University during the period from January 2002 to August 2007 were enrolled for this study. Patients were examined and diagnosed by radiologists according to the sonographic characteristics including lesion shape, margin, lesion boundary, orientation, echotexture and attenuation, and the results were all confirmed by surgery and pathological examination or biopsy. Informed consent to the protocol was obtained from all patients in this study and the study protocol was approved by the Institutional Ethics Committee of Harbin Medical University.

603 breast US images of 211 cases were obtained on a Vivid 7 system (GE Healthcare, Milwaukee, WI) with a 7.5–14 MHz linear-array transducer which has 38 mm scan width. US examinations were performed by an experienced US radiologist. The patients were in the supine position, or lateral decubitus position if the lesions were on the lateral of the breast. Both breasts were scanned directly and compared to each other. The lesions were scanned along different directions and angles, and the occipitofrontal, transverse and up-down diameters were measured.

Representative views of a lesion, a suspected lesion, or normal tissue were digitally recorded from frozen images and all images were stored in the disk of the ultrasonic equipment. US images were all compared with the pathological results. The number of images per lesion varied from one to six. The maximum diameters of the lesions are from 0.48 cm and 7.2 cm. The breast US images were saved in the database for analysis. The pathology results of surgery or biopsy were served as the gold standard in this study.

2.2. Observer study

603 original images of 211 lesions were processed using the newly developed speckle reduction algorithm based on two-dimensional textural homogeneity histogram and directional average filters. The homogeneity is used to describe the speckle features. The homogeneity value *HO* is defined using the texture information *F*, and image *I* is transformed from the gray domain *G* into the homogeneity domain. If the homogeneity value is high, the region is homogenous and there are few speckles. Otherwise, the region is non-homogenous and speckles occur. A 2D homogeneity histogram is built and the threshold is determined using the maximal entropy. The pixels are divided into two groups according to the threshold: a homogenous set, *Hs* and a non-homogenous set, *NHs*. Finally, the pixels in the non-homogenous set are handled according to the neighbor pixels iteratively.

Five breast radiologists (11, 13, 14, 20 and 22 years of clinical experience, respectively) blinded to the image acquisition procedure participated in the observer study. They interpreted the lesions independently. A fellow who did not read the images collected the pathological results, retrospectively found the corresponding images that had been acquired and stored by the radiologist, then she numbered the cases, stripped the identifiers from the images, mixed the order and present the cases to the

Table 1
Results of comparative assessment of the original and speckle-reduced images using four lesion features.

Criterion	Overall impression of speckle-reduced images after comparing with the original images (%)				
	Worse		Same	Better	
	– –	–	0	+	++
Edge definition	0	2.7	38.1	49.1	10.1
Edge regularity	0	3.8	47.5	46.7	2.0
Lesion texture	0	0.9	48.1	40.7	10.3
Lesion echogenicity	0	3.8	51.6	37.9	6.7

Table 2
The ultrasound diagnostic and pathological results using the original breast US images.

Pathology	Ultrasound					
	Benign	Probably benign	Possibly benign/malignant	Probably malignant	Malignant	Total
Benign	42	28	22	9	8	109
Malignant	8	6	18	19	51	102

Table 3
The ultrasound diagnostic and pathological results using the speckle-reduced images obtained by the proposed approach.

Pathology	Ultrasound					
	Benign	Probably benign	Possibly benign/malignant	Probably malignant	Malignant	Total
Benign	72	17	10	7	3	109
Malignant	3	6	13	10	70	102