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AN IMPROVED ADAPTIVE NEIGHBORHOOD CONTRAST ENHANCEMENT METHOD FOR MEDICAL IMAGES

Du-Yih Tsai*, Yongbum Lee*, and Reina Chiba**
*Department of Radiological Technology, School of Health Sciences, Niigata University
2-746, Asahimachi-dori, Niigata City, Niigata, 951-8518, Japan
**Graduate School of Health Sciences, Niigata University
2-746, Asahimachi-dori, Niigata City, Niigata, 951-8518, Japan

ABSTRACT

This paper presents an improved adaptive-neighborhood-contrast-enhancement (ANCE) method for improvement of medical image quality. The ANCE method consists of computing a local contrast around each pixel using a variable neighborhood whose size depends on the statistical properties around the given pixel. The obtained contrast image is then transformed into a new contrast image using a contrast enhancement function. Finally, a contrast-enhanced image is obtained by applying inverse contrast transform to the previous step. This technique provides the advantages of enhancing or preserving image contrast while suppressing noise. However, it has a drawback. The performance of the ANCE method largely depends on how to determine the parameters used in the processing steps. The present study proposes a novel method for optimal and automatic determination of threshold-value and neighborhood-size parameters using entropy. To quantitatively compare the performance of the proposed method with that of the ANCE method, computer-simulated images are generated. The output-to-input SNR ratio and the mean squared error are used as comparison criteria. Results demonstrate the superiority of the proposed method. Moreover, we have applied our new algorithm to X-ray CT images and echocardiograms. Our results show that the proposed method has the potential to become useful for improvement of image quality of medical images.

KEY WORDS

Medical image processing, contrast enhancement, noise reduction, entropy

1. Introduction

In recent decades a number of computer-aided diagnosis (CAD) schemes have been developed to aid in the interpretation of the increasing amounts of medical image data and clinical information [1]. In general the performance of CAD schemes largely depends on the image database employed. Therefore, in order to improve the performance of the schemes, enhancement of image quality of the image set is of importance.

Image quality is usually characterized by contrast, resolution, and signal to noise ratio. Adaptive neighborhood contrast enhancement (ANCE) is a recent approach to contrast enhancement [2, 3]. An adaptive neighborhood is constructed for each pixel, this pixel being called a seed pixel of the neighborhood [4]. In the ANCE, a variable shape and size neighborhood is defined using local characteristics of the image. Recently, Guis et al. [5] reported a novel ANCE technique. This ANCE method consists of computing a local contrast around each pixel using a variable neighborhood whose size depends on the statistical properties around the given pixel. The obtained contrast image is then transformed into a new contrast image using a contrast enhancement function. Finally, a contrast-enhanced image is obtained by applying inverse contrast transform to the previous step. This technique provides the advantages of enhancing or preserving image contrast while suppressing noise. However, it has a drawback. The performance of the ANCE method largely depends on how to determine the parameters used in the processing steps.

The present study proposes a method for optimal and automatic determination of threshold-value and neighborhood-size parameters using entropy. To quantitatively compare the performance of the proposed method with that of the ANCE method, computer-simulated images are generated. The output-to-input SNR ratio and the mean squared error are used as comparison criteria. Moreover, medical images obtained from various modalities are also used for performance comparison.

2. Methods

2.1 ANCE Method

Figure 1 shows the flowchart of the ANCE method proposed by Guis et al. [4]. Basic steps of the ANCE method are as follows:

1) Each pixel (i,j) is assigned an upper window $W_{\max}$ centered on it, whose size is $N \times N$ (N is an odd number). Let $I(i,j)$ be the gray level of pixel (i,j) in image I, and let T be a given threshold.

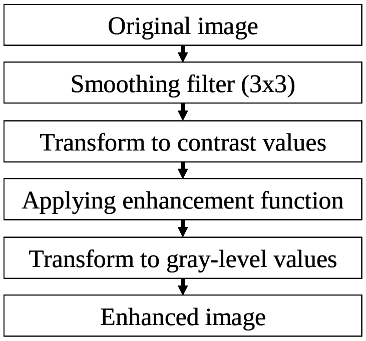


Fig. 1. Flowchart of the adaptive neighborhood contrast enhancement method proposed by Guis et al. [4].

2) Pixel (k,l) within $W_{\max}$ is assigned a binary mask value 0 if $|I(k,l)-I(i,j)|>T$, else it is assigned a binary mask value 1. This results in constructing a binary image.

3) The percentage P_0 of zeros is computed over the region between the external $(c+2)\times(c+2)$ and the inner $(c\times c)$ areas (c is an odd number). The process stops if this percentage is greater than 60% or if the upper window $W_{\max}$ is reached. Let c_0 be the upper c value beyond which the percentage P_0 is greater than 60%. The pixel (i,j) is assigned the window $W=(c_0+2)\times(c_0+2)$. The set of pixels having the mask value 1 is defined as "center", and the set of pixels having both the mask value o and which are eight-neighborhood connected at least to a pixel 1 is defined as "background".

4) A local contrast image is computed from

$$C(i,j)=\frac{|M_c(i,j)-M_b(i,j)|}{\max[M_c(i,j),M_b(i,j)]}\ , \qquad (1)$$

where, $M_c(i,j)$ and $M_b(i,j)$ are the mean values in image I of pixels labeled as the center and as the background regions around pixel (i,j), respectively.

5) The local contrast image C is then transformed into a new image C' using

$$C'(i,j)=F[C(i,j)]\ , \qquad (2)$$

where F is a contrast-enhancement function depending on the features to be detected. For example, the sigmoidal function or the trigonometric function is used.

6) A new image E is obtained by the process of inverse contrast transform using

$$E(i,j)=M_b(i,j)[1-C'(i,j)] \quad \text{if} \quad M_b(i,j)\ge M_c(i,j) \qquad (3)$$

$$E(i,j)=\frac{M_b(i,j)}{1-c'(i,j)} \quad \text{if} \quad M_b(i,j)<M_c(i,j)\ . \qquad (4)$$

7) Repeat step 1 to step 6 for each pixel in the image I.

2.2 Our Proposed Method for Parameter Determination

Two of the most important parameters used in the ANCE method are the threshold value T and the percentage P_0 of zeros computed over the region between the external and the inner areas. Guis et al. empirically used T=5 for thresholding and P_0=60% for determining neighborhood size in their study [4].

In this current study, we use a method for optimal and automatic determination of threshold value and neighborhood size from the viewpoint of information amount. Namely, the two parameters are determined when the entropy of the image I is at its maximum. The detail of determination process is described as follows.

1) Determination of the threshold value T: Let d be the difference between the maximum and minimum pixel values in the region of interest (ROI) whose size is $W_{\max}\times W_{\max}$. The value of T is then in the range of $0\le T\le d$. When the maximum entropy in the ROI is obtained by varying threshold value, this threshold value is regarded as T. The entropy of the ROI is given by

$$ENT(t)=-p_{0t}\log_2 p_{0t}-p_{1t}\log_2 p_{1t} \quad (0\le t\le d) \qquad (5)$$

where $ENT(t)$ is the entropy of the binary image obtained using a threshold value t, p_{0t} and p_{1t} are the probability of pixel value=0 and that of pixel value=1 in corresponding binary image, respectively. All the values of $ENT(t)$ in the range of $(0\le t\le d)$ are computed. The value of t is considered as T when $ENT(t)$ is at its maximum.

2) Determination of the neighborhood size: The entropy in $c\times c$ area is calculated, where $0\le c\le N$. The value of c is used as the neighborhood size when entropy is at its maximum.

3. Performance Assessment

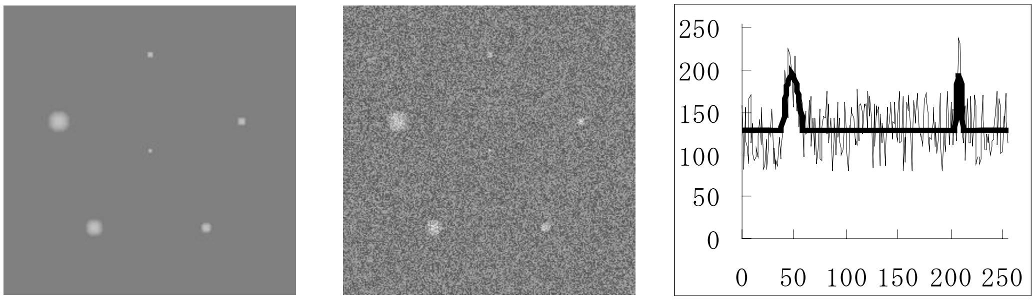
In order to demonstrate the effectiveness of the improved method, computer-simulated images of breast calcifications were used for quantitative evaluation. Five different contrast levels (from 10% to 50%; with a step size of 10%) and three noise levels (signal to noise ratios =10dB, 18dB, and 22dB) for each contrast level were generated. Therefore a total of 15 compute-simulated images were employed. The images consist of 256×256 pixels. The images were coded on 256 gray levels and the background level was set at gray level of 128. Figure 1 shows an example of computer-simulated image related to breast calcifications.

Performance comparison was made among the proposed improved method, Guis's ANCE method, 5×5 smoothing filter, and 5×5 median filter. Two criteria, namely, output-to-input SNR and the mean-squared-error (MSE), were used to quantitatively evaluate the four algorithms on computer simulated images. The output-to-input SNR parameter (called ρ) is defined as the ratio

$$\rho=\frac{SNR_{out}}{SNR_{in}}\ , \qquad (6)$$

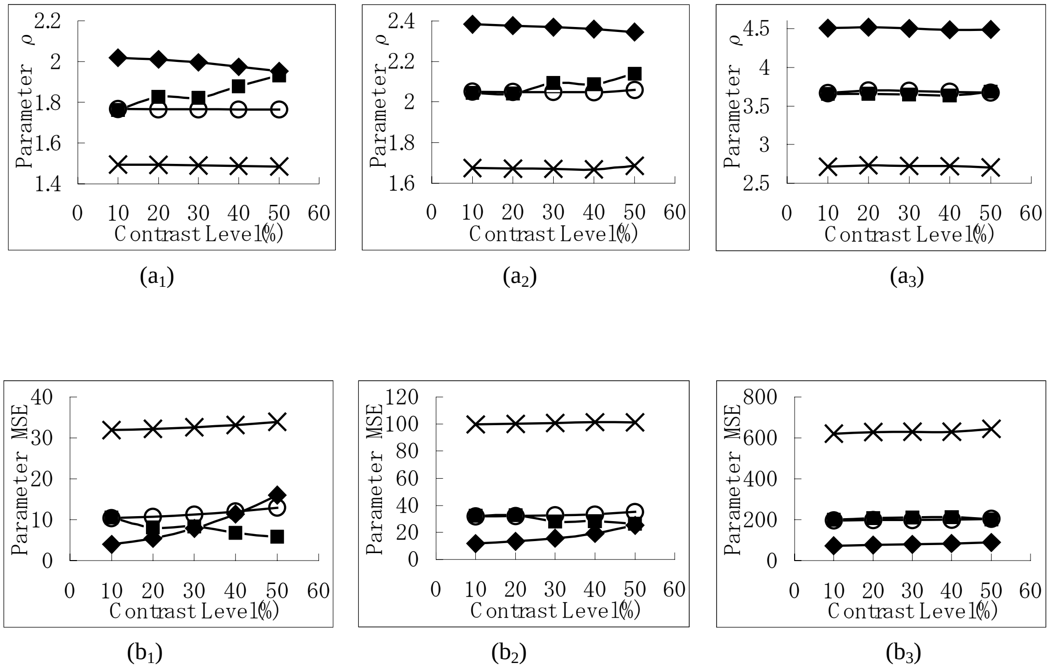
where SNR_{out} and SNR_{in} are the SNR after and before processing, respectively.

The MSE is calculated between the noise-free image f and the result $\hat{g}$ of the enhancement process on the input noisy image g:



(a) (b) (c)

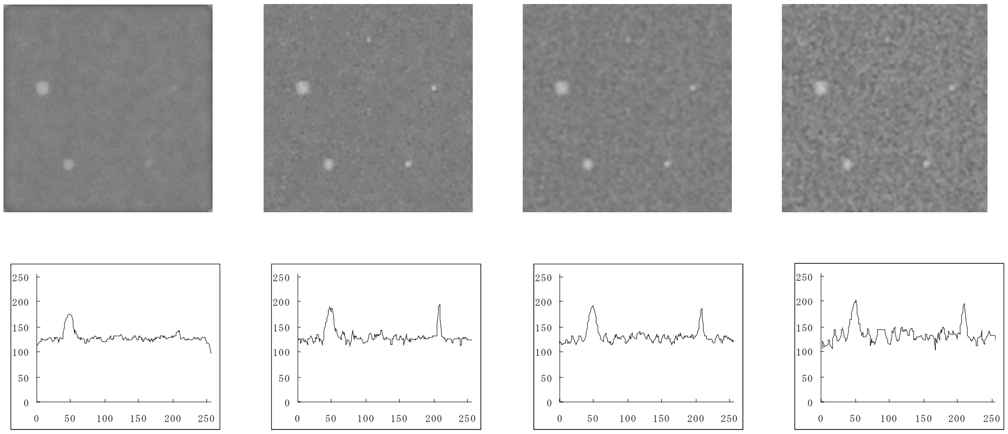
Fig. 1 Computer-simulated image of breast microcalcifications: (a) microcalcification noise-free image with a 30% contrast level, (b) noisy image with a SNR=18dB, (c) horizontal profile of both images (a) and (b) passing through the two different sizes of microcalcifications.



(a_1) (a_2) (a_3)

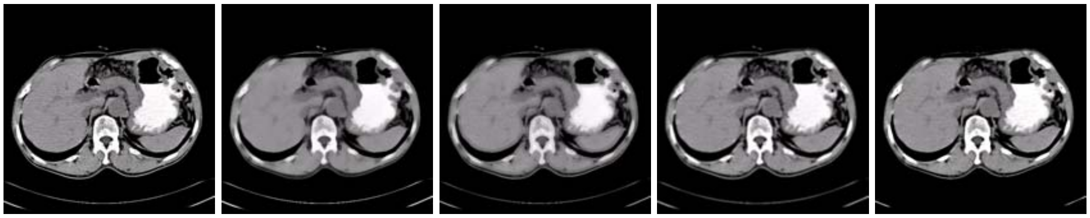
(b_1) (b_2) (b_3)

Fig. 2 Parameters ρ and MSE versus contrast level for computer simulated microcalcifications: (a_1), (a_2), and (a_3) results for parameter ρ at SNR=23dB, 18dB, and 10dB, respectively; (b_1), (b_2), and (b_3) results for parameter MSE at SNR=23dB, 18dB, and 10dB, respectively, where ■-conventional method , ◆-improved method , ○-5×5 smoothing filter, ×-5×5 median filter.



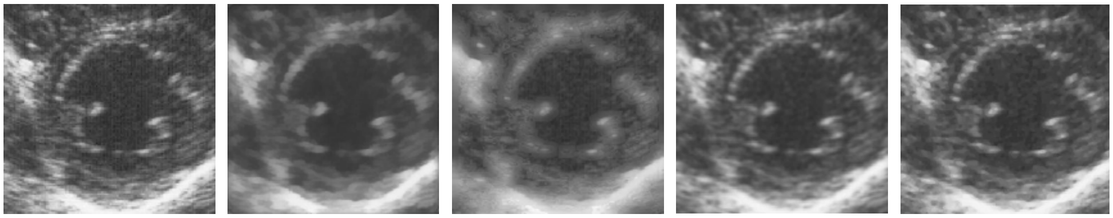
(a) (b) (c) (d)

Fig. 3 Results obtained on the microcalcification image shown in Fig. 1 and corresponding horizontal profiles using (a) the proposed method, (b) Guis's ANCE method, (c) 5×5smoothing filter, and (d) 5×5 median filter.



(a) (b) (c) (d) (e)

Fig.4 Original and processed CT liver images. (a) original image, (b) image obtained using the proposed method, (c) image obtained using Guis's ANCE method, (d) image obtained using 5×5 smoothing filter, and (e) image obtained using 5×5 median filter.



(a) (b) (c) (d) (e)

Fig. 5 Original and processed echocardiograms. (a) original end-diastole image, (b) image obtained using the proposed method, (c) image obtained using Guis's ANCE method, (d) image obtained using 5×5 smoothing filter, and (e) image obtained using 5×5 median filter.

$$MSE = \frac{\sum_{i=1}^{a}\sum_{j=1}^{b}[f(i,j)-\hat{g}(i,j)]^2}{a\times b} \quad , \qquad (7)$$

where a and b are the numbers of pixels on the horizontal and vertical directions, respectively.

It is noted that ρ is higher when much more noise is removed, whereas the MSE value is smaller when the image is denoised and the structure is preserved. Figure 2(a_1), 2(a_2), and 2(a_3) shows the results of ρ versus contrast at SNR=23dB, 18dB, and 10dB, respectively. The improved method gives best results. Figure 2(b_1), 2(b_2), and 2(b_3) shows the results of MSE versus contrast at SNR=23dB, 18dB, and 10dB, respectively. Similarly, the improved method gives best results. Figure 3 shows the images and the corresponding profiles obtained after applying the proposed method, Guis's ANCE method, 5×5smoothing filter, and 5×5 median filter. Visual observation demonstrates the superiority of the proposed method. Figures 4 and 5 show the results obtained after applying four different methods to clinical CT image and ultrasonic image. It is noted from visual evaluation that the images processed using the improved method give the best results.

4. Conclusion

In this paper we have described an improved ANCE method for enhancement of medical image quality. The improved method was based on the algorithm proposed by Guis et al. The feature of the improved method is to automatically determine the optimal threshold-value and neighborhood-size parameters using entropy. Computer-simulated images were generated to quantitatively evaluate the effectiveness of the proposed method in terms of output-to-input SNR and the mean-squared error. The proposed method was also applied to clinical echocardiograms and CT images. Results show that our proposed method performed well and clinically useful.

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