Digital Mammography Image Enhancement Using Improved Unsharp Masking Approach

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***Abstract*—Characteristics of the lesions in digital mammography images will be more clear after image enhancement, which can increase the detection rate of early breast cancer. This paper proposes a modified unsharp masking approach based on an improved high-pass filter. Experimental result of digital mammography image enhancement proves that the proposed method can effectively extrude the edges of lesions and at the same time can suppress the noises in uniform background areas.**

Keywords: unsharp masking; image enhancement; mammography

I. Introduction

Breast cancer is one of the common female malignant tumors. In Europe, the mortality of advanced breast cancer is 1/9[1]. Report of American Cancer Society[2] and a large amount of experimental data confirmed that early diagnosis of breast cancer can effectively save life and increase therapeutic schemes options. Characteristics of the lesion edge (for example, whether the edge is smooth) will be more clear after the digital mammography images are enhanced by computer, which is absolutely necessary to increase the detection rate of early breast cancer. According to statistics, the mortality of patients with breast cancer has decreased by 18% - 40%[3] thanks to the application of X-ray mammography.

Unsharp masking(UM) is a common method of image edge enhancement. In the UM technique, via a high-pass filter, scaled version of the high frequency part of an image is added to the image itself to extrude the edges and details. The conventional linear UM is simple and works well in many applications, but it suffers from two main shortcomings. First, due to the application of the linear high-pass filter, the details and noises are enhanced at the same time so in the uniform areas even slight noises are obvious; Secondly, It enhances high-contrast areas much more than the other areas. Consequently, some undesirable overshoot artifacts may appear in the output image.

To solve these problems, various approaches have been suggested. Unsharp masking with adaptive superposition factor adjustment is proposed by Se' bastie[4]; The cubic unsharp masking is suggested by Ramponi[5]. Processing results of these methods are much better the linear UM, but in the flat areas there are still some unpleasant artificial noises. The adaptive unsharp masking is described by Polesel in [6], which builds two filters respectively in the horizontal and vertical directions based on the anisotropy of the sensitivity of details of human vision in different directions, and adjusts the enhancement factor of the adaptive filter according to the local details level. This approach is the most effective but very complicate, so it is not suitable for the processing of high resolution digital mammographs (usually have a file size in tens of MB). To reduce the computational complexity, unsharp masking methods based on region segmentation (RS-UM) are suggested[7,8]. These methods are developed on the basis of the adaptive unsharp masking and work well in many applications, but due to the conventional high-pass filter they use, their enhancement of details and edges is not effective enough. This paper introduces an improved high-pass filter using a new convolution template, which has a good effect on enhancing area targets as well as point targets. So combining with the advantages of UM based on region segmentation and the improved high-pass filter, the new approach can effectively extrude the edges of lesions especially when using low enhancement factors and at the same time can inhibit the noises in uniform background areas.

II. Method

A. Linear UM

In the unsharp masking algorithm, the enhanced image $D_P(x, y)$ can be obtained from the input image $D_0(x, y)$ as

$$D_P(x,y) = D_0(x,y) + K(x,y) \times G(x,y) \tag{1}$$

where $K(x, y)$ is the positive enhancement factor that controls the level of contrast enhancement achieved in the output and $G(x, y)$ is the unsharp term computed as the output of a linear high-pass filter. In linear unsharp masking method, the enhancement factor $K(x, y)$ is a constant and the unsharp term $G(x, y)$ can be expressed as

$$G(x,y) = D_0(x,y) - \frac{1}{mn}\sum_{j=1}^{n}\sum_{i=1}^{m} D_0(x_i, y_j) \tag{2}$$

The conventional linear UM is simple and has a good enhancement effect, but due to the linear high-pass filter it uses, the details and noises are enhanced at the same time so in the flat areas even slight noises are obvious; and it is easy to generate some undesirable overshoot artifacts in the high-contrast areas[9].

B. UM Based on Region Segmentation

These methods divide the original images into low-detail region, medium- detail region and high- detail region.

For the digital mammographs, the low- detail region corresponds to the low-frequency part of images such as breast tissues; the medium- detail region corresponds to the characteristics like masses because the change rate of gradient between masses and its surrounding background is commonly at a low level; and the high- detail region means the high-frequency part such as calcifications. To classify which of the three regions each pixel of the input image belongs to, the local variance computed over a 3 × 3 pixel block is defined as

$$v_i(n,m)=\frac{1}{9}\sum_{i=n-1}^{n+1}\sum_{j=m-1}^{m+1}(x(i,j)-\bar{x}(n,m))^2 \tag{3}$$

where $\bar{x}(n,m)$ is the average luminance level of the same 3 × 3 pixel block. Define τ_1 and τ_2 as two threshold valves where $0<\tau_1<\tau_2$, We classify the input signal as belonging to the low-detail region if $v_i(n, m)<\tau_1$, a medium-contrast area if $\tau_1 \leqslant v_i(n, m)<\tau_2$, and a high-detail area if $v_i(n, m)\geqslant \tau_2$. To suppress the noises in smooth areas of background, enhance the details in medium-contrast area and avoid overshoot artifacts, the enhancement factor $K(x, y)$ in (1) is defined as

$$K'(x,y)=\begin{cases}1 & if\ v_i(n,m)<\tau_1 \\ \alpha_{dh}(>1) & if\ \tau_1 \le v_i(n,m)<\tau_2 \\ \alpha_{dl}(1<\alpha_{dl}<\alpha_{dh}) & if\ v_i(n,m)\ge\tau_2\end{cases} \tag{4}$$

where α_{dh} and α_{dl} is a upper limit and intermediate value of the enhancement factor respectively, so (1) can be represented as

$$D_P(x,y)=D_0(x,y)+K'(x,y)\times G(x,y) \tag{5}$$

C. UM Adopting Improved High-pass Filter

The high-pass filter employed by UM based on region segmentation is conventional high-pass filter like Laplace template or the mean template, it leads to such a problem: the enhancement result of details and edges will not be remarkable enough. This paper introduces an improved high-pass filter to ameliorate the sharpening effect especially when using low enhancement factors. The basic principle of the improved high-pass filter is firstly complete the prediction of background information through a low-pass filter, then subtract the predicted background from input image to get the filtered image which background information is suppressed. The algorithm flow is showed in Fig. 1.

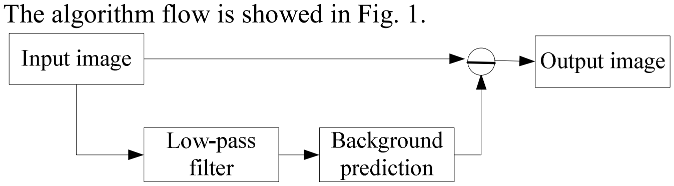


Fig. 1. algorithm flow of improved high-pass filter

Expression of improved high-pass filter[10] is given as

$$G_H(x,y)=(1+\lambda)D_0(x,y)-B(x,y) \tag{6}$$

where $G_H(x, y)$ is the output image, $D_0(x, y)$ is the input image, $B(x, y)$ is the predicted background information via a low-pass filter, and λ is an adjustable parameter which adjustment range is 0~1. When processing area targets, increasing λ can reserve more original information, while when processing point targets, more high-frequency characteristics can be reserved if λ is set to be zero.

The low-pass filter is implemented via a convolution calculation which expression is defined as

$$B(x,y)=D_0(x,y)H(m,n) \tag{7}$$

where $H(m, n)$ is the 5×5 template of convolution kernel, which expression is

$$H(m,n)=\frac{1}{40}\begin{bmatrix}2&2&2&2&2\\2&1&1&1&2\\2&1&0&1&2\\2&1&1&1&2\\2&2&2&2&2\end{bmatrix} \tag{8}$$

Then by substitution of the improved high-pass filter into (5), expression of UM adopting improved high-pass filter can be obtained as

$$D_P(x,y)=D_0(x,y)+K'(x,y)\times G_H(x,y) \tag{9}$$

Combining with UM based on region segmentation and the improved high-pass filter, the new approach are expected to have a better effect on extruding the edges of lesions when using low enhancement factors. In fact, parameter λ can also be adjusted segmentally according to the local dynamics of mammographic images as part of the enhancement factor.

III. RESULT AND DISCUSSION

Then experiment on applying our method to enhance partial of a digital mammograph is implemented and the performance of our algorithm is compared with those of the linear unsharp masking, the cubic unsharp masking algorithm and unsharp masking based on region segmentation. The original image is showed in Fig. 2 and processing results of various unsharp masking algorithm are showed in Fig. 3. Parameters employed in the enhancement experiment can be seen in TABLE I.

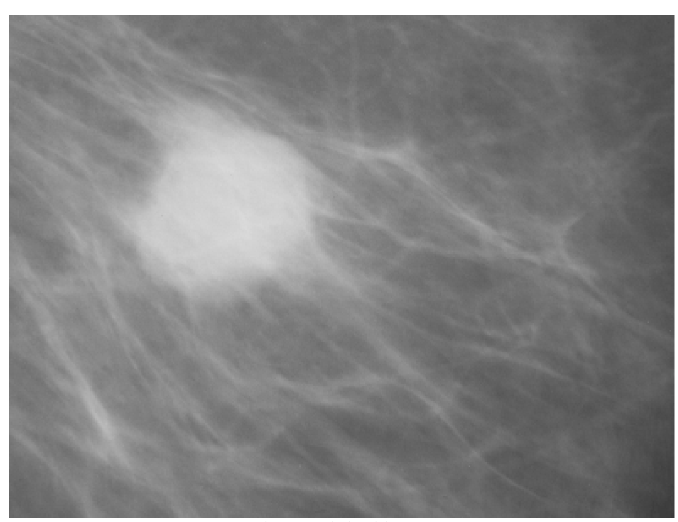
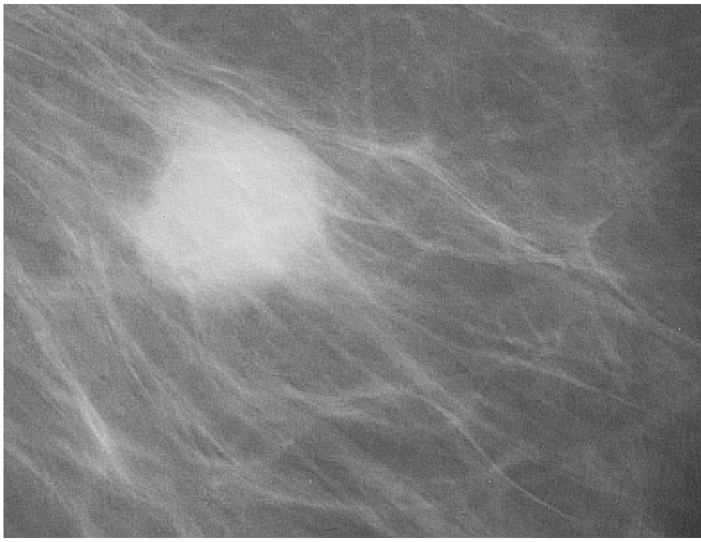
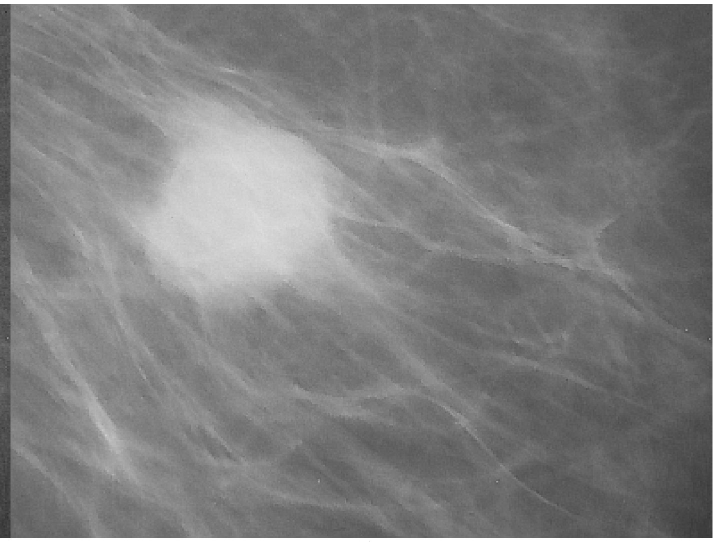


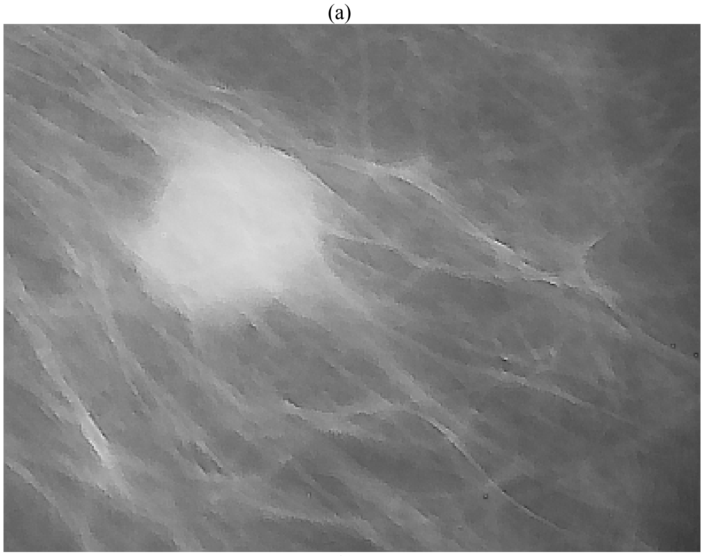
Fig. 2. original image[11]



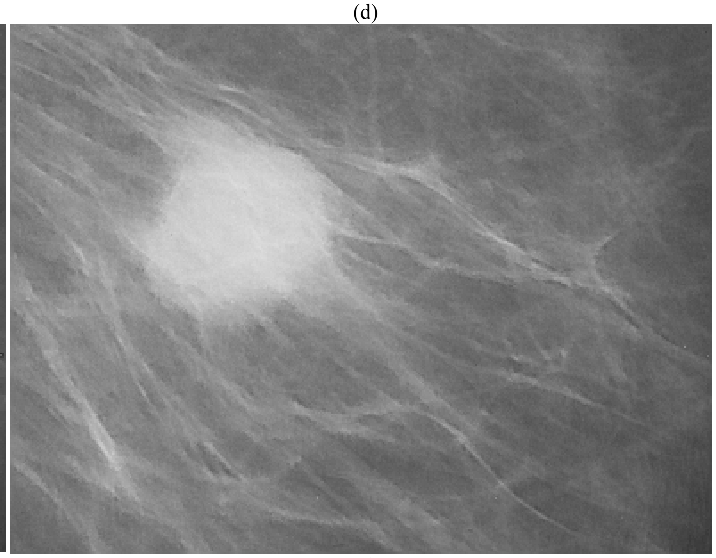
(a)



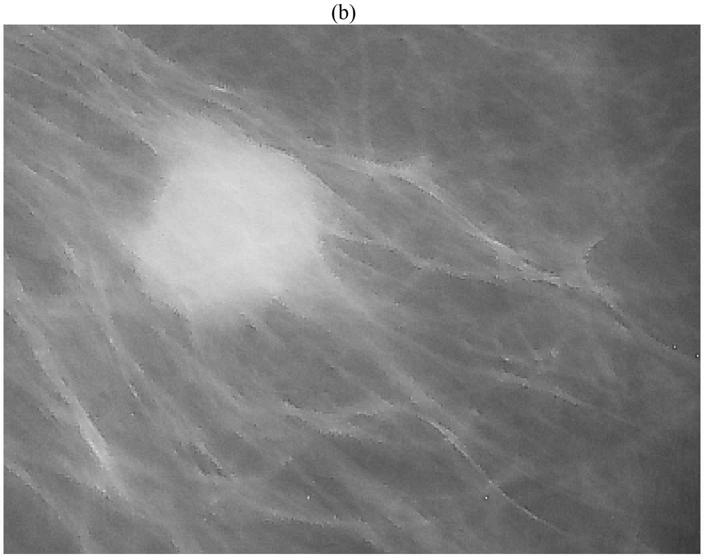
(d)



(b)



(e)



(c)

Fig. 3. Processing results of various unsharp masking algorithm: (a) linear UM processing; (b) cubic UM processing; (c) UM based on region segmentation using high enhancement factors processing; (d) UM based on region segmentation using low enhancement factors processing; (e) the proposed UM method adopting improved high-pass filter.

TABLE I. PARAMETERS EMPLOYED IN THE ENHANCEMENT EXPERIMENT

algorithm	**parameters**
linear UM	λ =3
cubic UM	λ =0.05
RS-UM using high enhancement factors	τ_1 =20, τ_2 =80, α_{dl} =7, α_{dh} =9
RS-UM using low enhancement factors	τ_1 =20, τ_2 =80, α_{dl} =3, α_{dh} =5
the proposed UM method adopting improved high-pass filter	τ_1 =20, τ_2 =80, α_{dl} =3, α_{dh} =5 , λ =0

In the processing of unsharp masking, there is no quantization method to measure the sharpening effect or to calculate the ratio of overshoot artifacts, so the best way is judging with human eyes. But to analysis the enhanced digital mammographs with a visual indicator, this paper uses DSM as an assistant evaluation parameter. DSM is an evaluation method based on probability distribution[12], which is defined as

$$\begin{cases} DSM = (|D_2 - \mu_B^E| + |D_2 - \mu_T^E|) - (|D_1 - \mu_B^O| + |D_1 - \mu_T^O|) \\ D_1 = \dfrac{\mu_B^O \sigma_T^O + \mu_T^O \sigma_B^O}{\sigma_B^O + \sigma_T^O} \qquad (\sigma_B^O + \sigma_T^O \neq 0) \\ D_2 = \dfrac{\mu_B^E \sigma_T^E + \mu_T^E \sigma_B^E}{\sigma_B^E + \sigma_T^E} \qquad (\sigma_B^E + \sigma_T^E \neq 0) \end{cases} \quad (10)$$

where μ_B^O, σ_B^O, μ_T^O, σ_T^O are the mean and standard deviation of the grayscales comprising the background and target area of the original image respectively. And μ_B^E , σ_B^E , μ_T^E , σ_T^E correspond to the mean and standard deviation of the grayscales after the enhancement. Ideally, the measurement should be greater than zero; the greater the DSM value, the better the quality of enhancement; if the value is below zero, it means that the contrast is not well enhanced. In Fig. 2 we select the mass and part of mammary ducts around the mass as the target area, and the rest of the image are considered as the background area. DSM values of digital mammographs processed by various unsharp masking methods are listed in TABLE II:

TABLE II. DSM VALUES OF DIGITAL MAMMOGRAPHS PROCESSED BY VARIOUS UNSHARP MASKING METHODS

algorithm	**DSM value**
linear UM	0.0044
cubic UM	-0.0040
RS-UM using low enhancement factors	3.6607e-004
RS-UM using high enhancement factors	-0.0024
the proposed UM method	0.0399

According to the observation of Fig. 3 and combining with the results in TABLE II, conclusions can be drawn as follows.

1) Linear UM works well to enhanced the details and edges of masses, so it get a DSM value above zero, but in the uniform background areas there are large amount of slight noises.
2) Cubic UM has a good effect on suppressing the background noises, but overshoot artifacts are generated in some high-contrast regions and there are few undesirable noises in flat areas.
3) When using low enhancement factor, UM based on region segmentation can effectively suppresses the background noises, but its enhancement effect of details and edges is not remarkable; However, when increasing the enhancement factor, there are obviously some overshoot artifacts, unexpected noises are also generated in uniform areas.
4) The proposed UM adopting improved high-pass filter has a comparatively good effect on sharpening the details and edges of lesions when using low enhancement factors, at the same time the noises and overshoot artifacts unexpected in flat areas are also suppressed effectively, so this method has got the highest DSM value (0.0399). The parameters used in the proposed UM approach are intentionally set to be the same values which are used in UM based on region segmentation when using low enhancement factors (where α_{dl} = 3 and α_{dh} = 5), this shows that the proposed UM comparatively has a better effect on extruding the details than UM based on region segmentation.

IV. CONCLUSION

The conventional linear unsharp masking method suffers from problems such as large amount of noises in background and overshoot artifacts in high- contrast areas; Unsharp masking based on region segmentation works well in many applications but its enhancement effect is not remarkable enough. This paper proposes a modified unsharp masking approach based on an improved high-pass filter. Experimental result of digital mammography image enhancement proves that, compared to the linear and region-segmentation based method, the proposed approach can effectively extrude the edges of lesions especially when using low enhancement factors and at the same time can inhibit the noises in uniform background areas.

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