REGION-BASED ENHANCEMENT OF DIGITAL CHEST RADIOGRAPHS

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ABSTRACT

In routine chest radiographs, the mediastinum is often underexposed and vascular structures are obscured by the diaphragm. We have developed a region-based processing algorithm to enhance contrast and brightness of selected anatomical regions, such as the mediastinum, without altering the other regions. We apply wavelet processing technique to segment a chest radiograph into different gray level regions and then apply different degrees of contrast enhancement procedure to them. The image enhancement is controlled by a proposed sigmoid function. The enhanced images showed improved visualization in the mediastinum area over the original unprocessed chest radiographs. Furthermore, the visibility of vascular structures which are obscured by the diaphragm and mediastinum is improved.

Keywords: Chest radiography, wavelet processing.

1. INTRODUCTION

One of the most challenging tasks in diagnostic radiology is to generate clinically useful images with improved visualization for diagnosis. Global window-and-leveling of a digital chest radiograph often results in the enhancement of underexposed mediastinum area and the degraded visualization of the lung field, or vice versa. To solve the problem, localized enhancement of selected gray level regions is required [1, 2].

Unsharp masking (UM) technique [3, 4] has been widely used in crispening the edges and enhancing high frequency information of an image. Conventional digital UM methods are based on spatial operations, such as convolution with a spatial mask, performed on the original image. In general, there are two types of UM, linear and nonlinear [5, 6]. In the linear UM approach, a highpass filtered image is first multiplied by a constant weighting factor and added to the original image in a pixel by pixel manner. In the nonlinear UM approach, before being added to the original image, the highpass filtered image is weighted by the factors whose values depend on the pixel intensity of the original image. Rogowska and Sezan [2, 6] have done extensive studies on the evaluation of linear and nonlinear UM techniques to enhance digital chest radiographs. Normally, a spatial mask can only be used to generate an image containing a certain frequency band. Tachocs [7] used the linear combination of two "smooth" images generated by spatial lowpass filtering of two different mask sizes. The idea is to enhance not only high frequency (a small mask size) but also medium frequency components (a large mask size). Recently, wavelet processing, because of its ability in multiscale analysis, is being extensively investigated for many applications, such as image compression and mammographic feature enhancement [8]. By using wavelet filtering, an image can be decomposed into multiresolution subimages containing different localized spatial frequencies. Moreover, by composing the subimages of different frequency subbands, we can obtain different bandpass filtered images, i.e., images containing different frequency subbands.

A region-based multiscale analysis is developed to enhance different gray regions on digital chest radiographs. The algorithm utilizes wavelet filtering techniques to enhance the image features of selected anatomic regions-of-interest in a chest radiograph. First, we applied wavelet filtering technique to the original image and obtained two images, one containing mostly low frequency components and the other, high frequency components. The lowpassed image provides the information of where are the gray regions of interest. The highpassed image contains high frequency components, such as the vascular structures, which are to be enhanced. Secondly, the lowpass image is used as input to a gain control function which is implemented by using different variations of a sigmoid function. The gain control function generates different gains for different gray-level regions in the lowpass filtered chest image. Finally, the highpassed filtered image is weighted by the different gains and then added to the original image. We tested the algorithm on computed chest radiographs. It is shown by viewing that our method enhanced visibility of the spine and vascular structures in the mediastinum area without degrading the contrast and intensity of the lung field.
2. REGION-BASED ENHANCEMENT TECHNIQUES

A. Enhancement of High Frequency Components

The region-based enhancement (RBE) algorithm uses wavelet filtering technique to obtain a multiresolution hierarchy of simultaneously localized space and frequency information. The output image of the algorithm can be described mathematically as follows:

\[
I_{RBE}(x,y) = I_O(x,y) + G(I_L(x,y))I_H(x,y) \\
+ I_B(I_L(x,y))
\]

(1)

where \( I_O(x,y), \ I_L(x,y), \ I_H(x,y), \) and \( I_B(I_L(x,y)) \) are the pixel intensities of the original, lowpass, highpass, and the brightness controlling images, respectively. The gain \( G(I_L(x,y)) \) is a function of the pixel intensity of the lowpass image. Equation (1) can be viewed as a generalization of the linear and nonlinear UM techniques in which the gains are, respectively, a constant and a function of the original image (i.e., \( I_L(x,y) = I_O(x,y) \) in Equation (1)).

Lowpass and bandpass filtered subimages, are generated by using the wavelet filtering techniques. The wavelet filtered image consists of several multiscale and multifrequency subimages. By preserving or eliminating different frequency subimages in the multiresolution hierarchy, we can reconstruct lowpass and bandpass filtered images, respectively. The selection of the subband levels and the reconstruction of different subimages will generate filtered images consisting of different frequency components. For example, if we preserve only the lowest frequency subband for the reconstruction of a lowpass image, then the more levels, the lower the frequency components that will be kept in the reconstructed image. In other words, the filtered image will be “smoother” and more fine details of image features will be lost. In such a case, this effect of a large number of levels on the filtered image is equivalent to that of using a larger size spatial mask in the median filter and spatial averaging. Similarly, by reconstructing the high frequency subbands, we can generate an image containing only “details” (i.e., higher frequency components) in the original image. This process is equivalent to the spatial highpass filtering using convolution masks, such as Sobel and Laplacian filtering masks. First, the highpass filtered image is multiplied by the gains generated by the gain control function guided by the lowpass filtered image. Then, the weighted highpass image is added or subtracted from the original chest image. The resulting image will contain enhanced or suppressed high frequency components at the selective gray areas in the chest radiograph. For example, we can enhance the high frequency components in the mediastinum while preserve the information in the lung field.

A reconstructed chest radiograph from certain frequency subbands is weighted and then added to the original chest image. The weights for enhancing the less radiodense area, such as the lung field, of a chest radiograph can be obtained by Equation (2).

\[
f_1(x) = a_1 \text{sigmoid}(c_1(\frac{x}{x_{\text{max}}}) - b_1))
\]

(2)

where \( a_1 = 2\text{sigmoid}(c_1(1-b_1)) \), \( b_1 \) and \( c_1 \) control the threshold and rate of enhancement, \( b_1 < 1 \), and \( x_{\text{max}} \) is the maximum gray value of the lowpassed chest images with maximum weighting value of \( f_1(x_{\text{max}}) = 1 \). The weights for enhancing the more radiodense area, such as the mediastinum, of a chest radiograph can be obtained by Equation (3).

\[
f_2(x) = a_2 \text{sigmoid}(-c_2(\frac{x}{x_{\text{min}}}) + b_2))
\]

(3)

where \( a_2 = 2\text{sigmoid}(-c_2(1+b_2)) \), \( b_2 \) and \( c_2 \) control the threshold and rate of enhancement, and \( b_2 > -1 \), and \( x_{\text{min}} \) is the minimum gray value of the lowpassed chest images with maximum weighting value of \( f_2(x_{\text{min}}) = 1 \). The function sigmoid(y) is defined as

\[
\text{sigmoid}(y) = \frac{1}{1+e^{-y}}
\]

(4)

We can also enhance the high frequency components in both the low and high radiodense areas simultaneously. In our study, we let \( a_1 = a_2 = a \) and \( b_1, b_2, c_1, \) and \( c_2 \) be adjustable variables. To ensure the continuity of the weight changes at a typical gray value \( x = X_T \), \( b_1, b_2, c_1, \) and \( c_2 \) must satisfy the condition shown in Equation (5) which can be obtained by solving the equation \( f_1(X_T) = f_2(X_T) \). The gain control function is shown in Equation (6) where the area with gray values smaller and larger than \( X_T \) are controlled by the gains generated by \( f_1(x) \) and \( f_2(x) \), respectively.
\[
c_1 = -c_2 \frac{X_T + b_2}{X_{\min}} - \frac{X_T - b_1}{X_{\max}} 
\]
(5)

\[
f_3(x) = \begin{cases} 
    f_1(x), & x \leq X_T \\
    f_2(x), & x > X_T 
\end{cases} 
\]
(6)

The area with medium radiodensity can be enhanced by Equation (7).

\[
f_4(x) = \begin{cases} 
    1 - f_1(x), & x \leq X_T \\
    1 - f_2(x), & x > X_T 
\end{cases} 
\]
(7)

Since the sigmoid function (Equation (4)) is a strict increasing and continuous function, the functions \(f_1(x)\) and \(f_2(x)\) are strictly increasing and decreasing functions, respectively, of the gray values of the pixels in the lowpass filtered image. All functions \(f_1(x)\), \(f_2(x)\), \(f_3(x)\), and \(f_4(x)\) are continuous and their derivatives of any order exist and are continuous.

B. Adjustment of Brightness of Anatomic Regions of Interest

We use Equations (8) - (11) to adjust the image brightness, where \(B_1\), \(B_2\), \(B_3\), and \(B_4\) are the brightness constants which control the intensity of the different gray level regions.

\[
f_5(x) = B_1 f_1(x) 
\]
(8)

\[
f_6(x) = B_2 f_2(x) 
\]
(9)

\[
f_7(x) = B_3 f_3(x) 
\]
(10)

\[
f_8(x) = B_4 f_4(x) 
\]
(11)

In summary, the algorithm uses different variations of the sigmoid function (as shown in Equations (2), (3), (6), (7), and (8) - (11)) to enhance or reduce the frequency components and intensity of different gray regions of interest.

3. EXPERIMENTAL RESULTS

We applied the algorithm to enhance the mediastinum and diaphragm with minimum change of the lung field on the computed chest radiographs. Each computed chest radiograph has 10 bits per pixel. To achieve this goal, Equations (2) and (8) were used to enhance the frequency and reduce the intensity of the mediastinum, respectively. Specifically, the output image of the RBE algorithm is

\[
I_{RBE}(x, y) = I_0(x, y) + f_1(I_L(x, y))I_H(x, y) - f_5(I_L(x, y)) 
\]
(12)

The parameters \(b_1\), \(c_1\) (Equation (2)), and \(B_1\) (Equation (8)) equal to 0.8, 10, and 512, respectively. \(I_L(x, y)\) is the reconstructed lowpass image from the first and second level wavelet frequency bands. \(I_H(x, y)\) is the reconstructed highpass image from the fifth level wavelet frequency band. The enhanced images showed improved visualization over the original unprocessed chest radiographs. The RBE algorithm can be applied to posterior-anterior (PA) and lateral chest radiographs in either vertical or horizontal orientation. The contrast in the mediastinum is enhanced without altering the lung area (see Figures. 1(a) original and 1(b) RBE processed images). Furthermore, the visibility of vascular structures which are obscured by the diaphragm and mediastinum is improved (see Figures. 2(a) original and 2(b) RBE processed images). The original and enhanced lateral chest images are shown in Figures. 3(a) and 3(b), respectively. The artifact along the lung field boundary can be reduced by suppressing the high frequency component along the lung field locations [9, 10].

Figure 1. The (a) original and (b) enhanced mediastinum chest images.

Figure 2. The (a) original and (b) enhanced mediastinum and diaphragm chest images.


5. REFERENCES


