Study of Automatic Enhancement for Chest Radiograph

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Because of the large difference of the densities in the lung and other structures, the chest x-ray image behaves as a wide-range intensity distribution, which brings on a bit of difficulty to investigate the focus. In the paper, according to the intensity properties of the chest radiograph, the chest radiographic image is divided into three subregions, and a piecewise linear transformation model is established. An approach of automatic enhancement is presented, based on the gray-level normalization. The average enhanced ratios of three subregions of the normal and severe acute respiratory syndrome image are increased by 10.70% and 25.55%, respectively. The technique is proved to be effective through the evaluation of the improved images.

KEY WORDS: Medical image processing, image enhancement, chest radiograph, SARS

INTRODUCTION

The chest radiograph is usually employed to diagnose the diseases in the thorax. It is often used especially to identify the lung disease. Sometimes it is demanded to diagnose the infection state of the lung rapidly in an emergency, such as the severe acute respiratory syndrome (SARS).

Image enhancement for chest radiograph is performed to improve the visualization of tissues and structures by optimizing some parameters, e.g., contrast, brightness, spatial resolution, and noise level, to find out various diseases in the chest. But the digitized chest radiographs suffer from poor quality in most of situations, so that the details of lung and mediastinum cannot be distinguished easily.

Because the x-ray attenuation across the lung is lower than other contents, the image of the lung becomes darker than the others on the chest radiograph. The traditional techniques of image enhancement apply the linear or S-form transfor-

mation to change the brightness and contrast, and the histogram equalization is often used for improving visual effect, which are popular in many medical image work stations so far. Because they are operated on the global area, they cannot meet the improved requirements simultaneously for the different parts of chest radiograph. In recent years, several local image enhancement algorithms have been presented.¹⁻⁶ Some enhancement methods based on histogram equalization⁷⁻¹¹ and modern signal processing techniques^{12,13} to improve the effect of the chest radiograph are given also.

In the paper, according to the gray-level properties of the different areas of the chest radiographic image, the global image is divided into three sections, and the adjusting effects of the piecewise linear transformation are analyzed. An approach of automatic enhancement is given by combining the

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Fig 1. Divided parts of chest radiograph.

Fig 2. Gray-level transform of chest radiograph.

histogram equalization with the gray-level transformation. It is shown that the details of the whole chest image are sharper.

MATERIALS AND METHODS

Approval of the institutional review board of the Children Hospital of Shanxi Province was obtained prior to start of the study.

Analysis of Chest Radiograph and Automatic Enhancement Algorithm

The appearance of chest radiograph indicates the lung area to be darker because of lower mass density and the close-grained

structures brighter, such as spine, rib, and abdomen. According to the intensity of the different regions of chest radiograph, the image can be divided into three parts: subregion I standing for the lung part, subregion II being the spine, heart, and abdomen, and subregion III standing for the shoulders, as shown in Figure 1. The subregion I looks like darker, the subregion III brighter, and the subregion II brightest, especially in the abdomen area. The goal of the gray-level transformation is to achieve a flat intensity instead of strong black and white difference on the whole image for improving the visualization of the details.

We can adjust the brightness and contrast of the subregions with a piecewise linear transformation, i.e., $g(x,y) = L(f(x,y))$. The two or three piecewise linear transformation is often used in actual situation.

Aiming at the intensity properties of the chest radiograph, we adopt three piecewise linear transformation, as shown in Figure 2. The equation is expressed by

$$g(x,y) = \begin{cases} L_{C_1C_2}(f(x,y)) & 0 \leq f(x,y) < f_{C_2} \\ L_{C_2C_3}(f(x,y)) & f_{C_2} \leq f(x,y) < f_{C_3} \\ L_{C_3C_4}(f(x,y)) & f_{C_3} \leq f(x,y) \leq f_{C_4} \end{cases} \quad (1)$$

where

$$\begin{aligned} L_{C_1C_2}(f(x,y)) &= \frac{g_{C_2} - f_{C_2}}{f_{C_2}} f(x,y) + g_{C_1} \\ L_{C_2C_3}(f(x,y)) &= \frac{g_{C_3} - g_{C_2}}{f_{C_3} - f_{C_2}} f(x,y) + g_{C_2} - \frac{g_{C_3} - g_{C_2}}{f_{C_3} - f_{C_2}} f_{C_2} \\ L_{C_3C_4}(f(x,y)) &= \frac{g_{C_4} - g_{C_3}}{f_{C_4} - f_{C_3}} f(x,y) + g_{C_3} - \frac{g_{C_4} - g_{C_3}}{f_{C_4} - f_{C_3}} f_{C_3}. \end{aligned}$$

In Figure 2, the input corresponding with C_1C_2 , C_2C_3 , and C_3C_4 spans the gray-level range of the lung (subregion I), shoulder and top of spine (subregions II and III), and heart, abdomen, and middle and bottom of spine (subregion II), respectively, where $f_{C_1} = 0$, $f_{C_2} = 115$, $f_{C_3} = 153$, and $f_{C_4} = 255$ stand for the inputs of the point C_1 , C_2 , C_3 , and C_4 for an 8-bit digital image.

The enhancement effect for the chest radiograph is determined by adjustment of the points C_1 , C_2 , C_3 , and C_4 , which are described in the following.

C_1 adjusts the brightness and contrast of subregion I. The larger the slope of C_1C_2 is, the stronger the contrast is. The strong contrast is not expected usually because of an extra darkness. The contrast can be reduced with increase of brightness by increasing C_1 .

C_2 mainly adjusts the contrast of subregion I, and it almost does not affect other subregions. So we can alone change the output of C_2 to obtain the desired visualization of the lung region.

C_3 adjusts the brightness of subregions II and III, but hardly affects subregion I. The output of C_3 should not be larger; otherwise, the tops of subregions II and III are much more brighter, which causes the structures to be undistinguishable.

Fig 3. Approach of automatic enhancement for chest radiograph.

Fig 4. (a) Original normal chest radiographic image. (b) Processed image.

Fig 5. (a) Original SARS radiographic image. (b) Processed image.

C_4 adjusts the brightness and contrast of subregion II. It creates a negative effect when the output of C_4 is less than that of C_3 .

Approach of Automatic Enhancement for Chest Radiograph

Although we found out the regulation of the chest radiographic image, based on its intensity properties, the direct gray-level transformation with Equation (1) is not enough because of the different patients, types of x-ray radiographic equipment, and imaging conditions, and the chest radiographic results are distinct from each other. Therefore, the ideal effect cannot be achieved automatically only with the linear gray-level transformation. It is necessary to normalize the gray-level distribution of the image. The histogram equalization processing gives an approach to force the image histogram to become uniform. To make the linear transformation of Equation (1) suitable to various chest radiographic images, we may first obtain the image of uniform histogram by means of the histogram equalization, which is a basis for performing the linear transformation in the next step.

The histogram equalization is expressed by

$$p(s_k) = n_k/n \quad (k = 0, 1, 2, \dots, L-1) \quad (2)$$

where s_k is the k th gray-level value of the image $f(x,y)$, n_k is the pixel number possessing the k th gray-level value, n is the total pixel number of the image, and L is the total gray-level number.

The equalized image can be obtained using the following expression

$$H_k = \sum_{i=0}^k p(s_i) \quad (3)$$

In a word, the approach of the automatic enhancement for chest radiograph is shown in Figure 3, in which the piecewise linear transformation indicates Equation (1).

Table 1. Parameters applied in equation (1) for processing chest radiographic images

f_{C_1}	f_{C_2}	f_{C_3}	f_{C_4}	g_{C_1}	g_{C_2}	g_{C_3}	g_{C_4}
0	115	153	255	52	150	225	60

Fig 6. Subregion division of normal chest radiographic image.

RESULTS AND DISCUSSIONS

The results of the enhanced chest radiographic images by means of the presented approach are

shown in Figures 4 and 5. All of the applied parameters in Equation (1) are listed in Table 1. The values of g_{C_1} , g_{C_2} , g_{C_3} , and g_{C_4} are collected through the judgment of the radiologists by

Fig 7. Subregion division of SARS chest radiographic image.

Table 2. Three subregion standard deviations and enhanced ratios of normal and SARS chest radiographic image

Subregion number	Normal			SARS		
	Original image	Enhanced image	Enhanced ratio(%)	Original image	Enhanced image	Enhanced ratio(%)
I	8.80	9.47	7.61	9.37	10.60	13.13
II	10.02	10.43	4.09	6.58	9.81	49.09
III	9.27	11.16	20.39	9.35	10.70	14.44
Average value	9.36	10.35	10.70	8.43	10.37	25.55

the visualization effect after processing typical chest radiographs, so they may be applicable for most of the chest radiographs.

It is shown that three subregions are improved completely in Figures 4(b) and 5(b) by comparing with their original images, where there is an appearance of negative effect in subregion II because the output of C_4 is less than that of C_3 . It is easier to identify the pathological features of the small goblet of the lung for the SARS patient in Figure 5(b).

The normal and the SARS radiographic images are divided approximately in accordance with Figure 1, as shown in Figures 6 and 7, respectively. To measure the enhanced effect, we may calculate the standard deviation of every subregion image by use of the division of Figures 6 and 7. The larger the standard deviation is, the more distinguishable the image structures are. Three subregion images are evaluated with their standard deviations, as shown in Table 2. The average enhanced ratio of three subregions of the normal and SARS images is increased by 10.70% and 25.55%, respectively. Thus, the processed images are obviously superior to the original ones.

CONCLUSIONS

Aiming at the automatic enhancement for the chest radiograph, the piecewise linear transformation model is established by dividing the image into three subregions, based on its gray-level properties. The histogram equalization is essential in attaining a normalization of the image before performing the piecewise linear transformation. The methodology of the automatic enhancement is proved to be effective through the evaluation of the improved images in the application of normal and SARS radiographic images. It provides an

approach for the automatic enhancement and recognition of chest radiograph in the clinic.

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