A Method for Enhancing Dot-like Regions in Chest X-rays Based on Directional Scale LoG Filter

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Abstract

Chest radiography for detection of lung nodules can benefit from enhancement of suspicious structures in the lung-in many cases, these are regions containing a spherical structure and appear as a dot. In order to visualize such areas in chest radiography more clearly, and to better determine the extent of that region, in this paper, an improved Laplacian of Gaussian (LoG) filter based method for enhancing dot-like regions in chest X-rays is proposed. By permitting different scale values in the X and Y direction, the proposed method allows specific directional textures in lung nodules to be enhanced. To compensate for the visual vague problem caused by Gaussian operation, a visual correction factor is also introduced. Experiments show that the technique proposed in this paper can effectively enhance the contrast between lung nodules and its surrounding tissue, and make lung nodule easier be detected by human visual perception.

Keywords: Image Enhancement; Laplacian of Gaussian (LoG); Directional Scale; Chest Radiograph

1 Introduction

Chest radiography serves as a common diagnostic tool for detection of early stage lung cancers which often appear as solitary pulmonary nodules. However, detection of solitary pulmonary nodules in chest radiography image is very challenging due to the appearance of superimposed anatomical structures and low nodule contrast with respect to its background in the lung field in Chest X-ray image [1]. It has been reported that radiologists can fail to detect pulmonary nodules on chest radiographs as many as 30% of positive cases [2]. As a basic image preprocess technique, image enhancement does a great effect on improving the visual of chest X-Rays, and a lots of
researches have also been reported in recent years [2, 3], e.g. adaptive histogram equalization [4], un-sharp masking [5] and the Laplacian filtering [6]. These previous works have been extremely positive and have helped to improve radiologist performance for diagnostic accuracy. However, an adaptive histogram equalization technique brings a limited improvement, because fixed contextual regions cannot adapt to features of different size. Techniques of unsharp masking are less efficient for images containing a wide range of features because of their single scale properties. The major drawback of the Laplacian filtering is the absence of explicit noise suppression model that can cause amplification of the noise or artifacts. More ever, it should be noticed that all image enhancement methods mentioned above work on enhancing a whole chest X-Ray, and as a result, these methods enhance not only nodules, but also other anatomic structures such as ribs, blood vessels, and airway walls. Therefore, nodules are often detected together with a large number of false positives caused by these normal anatomic structures. So to make nodule more visible, it is very important and valuable to study technologies for enhancing lung nodules contrast with respect to its background but suppressing other anatomic structures in chest X-Rays. This clinical importance of chest radiographs and their associated difficulties in diagnostic interpretation are the main motivation for the study in this paper. Bearing the aim of the present work of this paper in mind, the following facts must be carefully considered. Typically, a lung nodule is a roughly spherical object and has a density comparable to water, which is higher than the surrounding lung parenchyma. Consequently, lung nodules in chest radiographs usually appear as low contrast dot-like patterns embodied in a complex background which can easily obscure them (as shown in Fig. 1). In addition, normal anatomical structures are responsible for very troublesome masking effects because that various anatomical structures are likely to create gray level patterns which strongly resemble nodules when observed by conventional X-ray imaging.

Both multi-orientation and multi-resolution are known as features of the human visual system [4]. There exist cortical neurons which respond specifically to stimuli within certain orientations and frequencies. Since the human visual system is sensitive to high frequency signals, and the visibility of the high frequency signals will become low when the high frequency signals of an object are embedded in high frequency background signals [4]. Based on what mentioned above, it can be seen that lung nodule enhancement could be conceived as a filtering process that searches for any dot-like region (where a potential nodule may happen to occur) in a chest x-ray image. By a proper amplification of the high frequency components in chest radiograph image, the visual perception of radiograph would be improved. The technique involved in such vision is convolution with a “Mexican hat” type filter. An approximation to a “Mexican hat” type filter can be given
with a Difference of Gaussian (DoG) or the opposite of a Laplacian of Gaussian (LoG). In this study, the Laplacian of Gaussian filter [5] was employed to perform this task. Compared with the DoG filter, the LoG filter has a high central lobe which can provoke a high intensity transmission. Counting the texture directional of lung nodule, the LoG filter is modified by assigning different scale value in X and Y direction, respectively. Compared with the conventional LoG filter, the main advantage of the improved filter is its orientations in enhancing different direction texture detail of lung nodules in chest X-Ray images. To compensate for the visual vague of the enhanced image caused by Gaussian operation, a visual correction factor is also introduced. Experiments show that the technique proposed in this paper can effectively enhance the contrast between lung nodules and its surrounding tissue, and make lung nodule more easily be detected by human visual perception. The rest of this paper is organized as follows. In Section II, the conventional LoG filter is introduced firstly, and then we describe the improved LoG filter and the nodule enhancement method employed in this study. In Section III, we present the database used in this study firstly, and then the experiments are described in detail. In the last section we give some conclusions.

2 Proposed Method

2.1 The Conventional LoG Filter [8]

The Laplacian is a 2-D isotropic measure of the second spatial derivative of an image. The Laplacian of an image highlights regions of rapid intensity change and is often used for edge detection. The Laplacian \( L(x,y) \) of an image with pixel intensity values \( I(x,y) \) is given as follows:

\[
L(x, y) = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}.
\]

Because the Laplacian is approximating a second derivative measurement on image, it is very sensitive to noise. To reduce its sensitivity to noise, the Laplacian is often applied to an image that first has been smoothed by a Gaussian smoothing filter. This combined filter is called Laplacian of Gaussian (LoG) filter. The 2-D LoG function centered on zero and with Gaussian standard deviation has the form:

\[
\text{LoG}_\sigma(x, y) = \frac{1}{\pi \sigma^4} \left(1 - \frac{x^2 + y^2}{2\sigma^2}\right)e^{-\frac{x^2 + y^2}{2\sigma^2}}.
\]

where \( \sigma \) is the Gaussian standard deviation. The Gaussian operator suppresses the influence of points away from the centre of the template, basing differentiation on those points nearer the centre. The standard deviation \( \sigma \) is chosen to ensure this action. The transform is circular-symmetric. This reveals that the LoG operator emits low and high frequencies (those close to the origin, and those far away from the origin). Fig. 2 illustrates a perspective plot of LoG filter with The Laplacian of Gaussian filter has a high central lobe (as shown in Fig. 2(a))) which can provoke a high intensity transmission, and make the LoG filter acts as a probe that calculates the difference in contrast within and outside the region of interest. The difference in contrast between the two regions will be high if we apply this kernel over a nodule since nodules have high values at the center (bright) and low values in its surrounding region (dark), as shown in Fig. 2(b).
This profile closely mimics the response of the spatial receptive field found in biological vision [4]. Biological receptive fields have been shown to have a circularly symmetric impulse response, with a central excitatory region surrounded by an inhibitory band.

2.2 Directional Scale LoG Filter

Many researches [9, 10] show that the human visual perception systems has the property of direction selectivity, viz. the human eye is more sensitive on luminance variation in a slope direction than that in verticality and horizontal. The fact, that when human eye focus on some a direction the luminance in this direction will be enhanced, shows the human eyes hold multi-frequency channels. Evermore, lung nodules in chest X-Rays may appears different texture in different viewpoint because of the natural of chest itself.

Based on what mentioned above, in this study, we do an improvement on the conventional LoG filter. The idea is as below: assigning different scale value $\sigma_x$ and $\sigma_y$ to LoG filter in X and Y direction respectively, this makes the filter has different frequency channel in X and Y direction respectively. As a results, the LoG filter can enhance lung nodules in chest X-Rays according to its natural directional characteristics. The improved operator is depicted as bellows:

$$LoG(\sigma_x, \sigma_y, n) = \left(\frac{x^2 - \sigma_x^2}{\sigma_x^4} + \frac{y^2 - \sigma_y^2}{\sigma_y^4}\right) \exp\left(-\left(\frac{x^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2}\right)\right)$$ (3)

Where both $\sigma_x$ and $\sigma_y$ approximate to $\frac{r}{\sqrt{2}}$ [11], and $r = \sqrt{x^2 + y^2}$.

Due to the smoothness of Gaussian function, when a chest X-Ray image is convoluted with a LoG kernel, some texture details in the chest X-Ray image are weaken. And as a result, the enhanced chest X-Rays seems a little blured. To solve this problem, we introduce a visual correct factor $\beta$ into above processed image, viz. $\beta \ast LoG(\sigma_x, \sigma_y, n)$.

2.3 Enhance Lung Nodules in Chest X-Rays Using the Improved LoG Filter

The implementation of the proposed method is summarized as followings:
Step 1 Compute the kernel of LoG operator for enhancing a region with spherical structure use the improved LoG filter from Eq. (3).

Step 2 Convolute the input chest X-Ray image with the improved LoG kernel computed in step1. The filtered image can be represented by

\[
L(x, y) = I(x, y) \otimes \text{LoG}(\sigma_x, \sigma_y, n)
\]  

where \(\otimes\) indexes the convolution operator. The LoG filter provides local mean of a chest X-ray image.

Step 3 Multiply the filtered image \(L\) with a display factor \(\beta\) for the reason of visual considerations.

Step 4 Subtract the LoG filtered image in step 3 from the original chest X-Rays, viz. \(\text{Output} = I - \beta \ast \text{LoG}(\sigma_x, \sigma_y, n)\)

After above image enhancement processes, regions within a spherical structure (where a potential nodule may happen to occur) in a chest radiograph image are of higher intensity, on average, than regions that are part of a non-spherical structure. This would lead to better contrast enhancement for nodules as rib edges would be normalized.

3 Experiments

The database used in our study consisted of 52 posterior anterior chest radiographs selected from the Japanese Standard Digital Image (JSRT) Database [12] developed by the Japanese Society of Radiological Technology, which is available publicly. The JSRT Database includes 154 abnormal chest radiographs, each with a solitary pulmonary nodule, and 93 non-nodule chest radiographs. These original screen-film images were digitized with a 0.175 mm pixel size, matrix size of 2048x2048 pixels, and 12 bits of gray scale. For computational efficiency, the size of the chest radiographs was reduced by a factor of 4 to 440x440 pixels with a 12 bit gray scale level by use of averaging. The absence and presence of nodules in the chest radiographs were confirmed by use of CT examinations.

In the following sections, the performance of the proposed method is evaluated via its effect on the visual of nodules in the chest radiograph (3.1) and by its effect on radiologists in detecting lung nodule in chest X-Rays (3.2).

3.1 Effect of the Proposed Method on the Visual of Nodules in Chest Radiographs

Fig. 3 shows some results of applying the proposed method in this paper to above mentioned database. It can be seen that in all original chest X-Rays (Fig. 3(a)), areas with a spherical structure (where a potential nodule may happen to occur) seem a little vague in visible since they are buried in noise and surrounded by background with a low contrast. However, as shown in Fig. (3b), in the enhanced chest X-Rays by using method proposed in this paper, these areas appear as bright convex spherical objects imbedded in dark regions in corresponding output.
images. As we can see, the enhanced regions in the chest radiograph closely match the regions discernible by our eyes.

A comparison of the proposed method with the conventional LoG filter based method and other existing methods described in [7], which have been proved effective in enhancing lung nodules in chest radiographs, are also provided. Part results are shown in Fig. 4. As it can be seen that all methods can enhance the contrast of dot-like regions in chest X-rays with respect to its background. However, in images enhanced with LoG filters, dot-like regions is more clearly with respect to its background than that in images enhanced with methods described in [7]. It also can be seen that some texture details in images enhanced with conventional LoG filter are lost, while that in images enhanced with the modified LoG filter are well preserved. This indexes that the method proposed in this study is superior to other existing methods in enhancing the contrast of nodules with respect to its background.

3.2 Effect of the Proposed Method on the Visual of Nodules in Chest

Three radiologists were invited to participate in this experiment. In this experiment, radiologists first were asked whether the cancer was present or absent in the original chest X-Ray, and they then marked their confidence level regarding the likely-hood of the presence of a cancer by using a continuous rating scale displayed on the monitor. After the radiologist marked the initial level of confidence, the nodule enhanced chest X-Ray was shown, and they again were asked to mark their confidence level. Table 1 lists the result of this experiment.
As we can see from Table 1, with aid of the enhanced chest X-Rays, the accuracy rate of radiologists were average improved by 9% (from 0.728 to 0.82). This result suggests that enhancing regions with spherical structures via improved LoG filter proposed in this paper is helpful for the improvement of accuracy of radiologist in lung nodule detection in chest X-Rays.

Table 1: the results of the experiment in section 3.2

<table>
<thead>
<tr>
<th>Radiologist</th>
<th>Only original chest X-Rays</th>
<th>Original chest X-Rays and enhanced chest X-Rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.739</td>
<td>0.835</td>
</tr>
<tr>
<td>B</td>
<td>0.726</td>
<td>0.824</td>
</tr>
<tr>
<td>C</td>
<td>0.719</td>
<td>0.802</td>
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<tr>
<td>Average</td>
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<td>0.820</td>
</tr>
</tbody>
</table>

4 Conclusions

In this paper, a method for enhancing spherical structure regions in chest X-Rays is developed based on directional scale LoG filter. The main advantage of the improved filter is the exploit of
the orientations of the LoG filter. Experiments show that the technique proposed in this paper not only effectively enhances the lung nodules in chest radiograph but also improves the visual effect of lung nodules in chest X-rays to make itself more suitable for human visual perception. However, it should be noticed that the results in this study is preliminary and more researches are required in the future.

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References


