Image enhancement on digital x-ray images using N-CLAHE

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IMAGE ENHANCEMENT ON DIGITAL X-RAY IMAGES USING N-CLAHE

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ABSTRACT

Digital chest radiography offers many advantages over film-based radiography, such as immediate image display, no film processing and room storage, wider dynamic range and lower radiation dose. In general, a raw X-ray image acquired directly from a digital flat detector contains poor quality of image, which may not be suitable for diagnosis and treatment planning. Therefore, a pre-processing technique is usually required to enhance image quality. This paper presents an improved image enhancement on digital chest radiography using the so-called N-CLAHE method, which is based on global and local enhancement. The proposed technique consists of two main steps. Firstly, intensity correction of the raw image is encountered by the log-normalization function which adjusts the intensity contrast of the image dynamically. Secondly, the Contrast Limited Adaptive Histogram Equalization (CLAHE) method is used for enhancing small details, textures and local contrast of the images. The proposed approach was tested using a radiographic survey phantom and a radiographic chest phantom and compared with conventional enhancement methods, such as histogram equalization, unsharp masking, CLAHE. The results show that the proposed N-CLAHE method yields great improvement on the pre-processing correction for digital chest radiography.

Index Terms— X-ray imaging, Image enhancement, CLAHE, Chest radiography

1. INTRODUCTION

A raw X-ray image acquired directly from a digital flat panel detector usually contains the poor quality of image, as a result, it cannot be used directly for medical diagnosis. Normally, image enhancement method is certainly integrated in the backend of X-ray processing before image display as shown in Fig. 1. Since it is an intellectual property and trade secret of the company, we need to develop our own algorithm to enhance X-ray raw images. This would increase visualization of the heart, lungs, airways, blood vessels, spine and chest.

Fig. 1: Process to enhance raw X-ray images

A number of articles have been published to improve the quality x-ray image, such as histogram equalization (HE), adaptive histogram equalization (AHE) and wavelet transform coefficients (WT) [1] [2] [3]. However, there are limitations about noise reduction and processing time. In diagnosis medical image, local detail may be more important than global contrast. The unsharp masking method (USM) is another well-known enhancement method [4] [5]. It can increase either sharpness or local contrast in smaller regions, while at the same time preventing an increase in the global contrast of the image. Although this improves image contrast, it may not be suitable for clinical assessment because the processed image may look artificial and some artifacts may be introduced in the image. Another well-known local enhance method is an adaptive contrast enhancement (ACE) [6] which used contrast gains (CG) to adjust the high frequency components of images but it spent more time to process. Moreover, one of the most popular and favorite methods for medical image enhancement is CLAHE [7]. Although CLAHE was applied to enhance small details, texture and local contrast of the images better, applying this method only may lead to overexpose or underexpose the X-ray image [8]. In this paper, we propose an improved image enhancement method that combines the log-normalized and CLAHE algorithms to gain image quality of the raw X-ray image acquired from the digital detector in the pre-processing stage.

2. METHODS

The poor quality of acquired raw images, that the authors aforementioned, are not good enough for chest X-ray diagnosis. Hence, to improve their image quality, we propose the so-called N-CLAHE method to increase the contrast of the images dynamically as well as to improve visibilily of anatomical structures.

2.1. The N-CLAHE Method

The N-CLAHE approach is the combination of the normalization function and the Contrast Limited Adaptive Histogram Equalization (CLAHE) method. The proposed technique consists of two main steps. Firstly, global intensity correction of the raw image is normalized by the log function with the blank scan image. Secondly, the calculation of further local contrast enhancement is operated by the CLAHE approach. The overview of the N-CLAHE is shown in Fig. 2

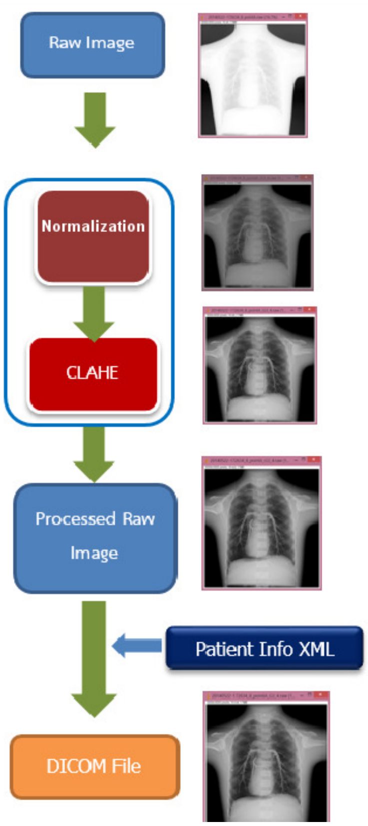


Fig. 2: The overview of N-CLAHE method

From Fig. 2, once the raw image is pre-processed, it combines the patient information as well as image and deice information into a DICOM (Digital Imaging and COmmucations in Medicine) file image, which is a standard for medical imaging modalities.

2.2. Normalization

Normalization is a process to change the range of pixel intensity values which based on Beer's law [9]. The purpose of dynamic range expansion in the digital X-ray applications is usually to produce an image with values suitable for display ($P_{Normalize}$) which can be described in the form as follows:

$$P_{Normalize} = \log\left(\frac{P_{Blank}}{P_{Raw}}\right) \tag{1}$$

where $P_{Normalize}$ is a normalized X-ray image, P_{Blank} is an X-ray image without an object and P_{Raw} is a typical X-ray image.

2.3. CLAHE

For local contrast enhancement, in this paper, we used CLAHE [7] that computes over different tile regions of the image based on histograms. Local details can therefore be enhanced even in the regions that are darker or lighter than most of the image. The CLAHE method was performed by limiting the amplification of the histogram on the image and then clipping the amplification of the histogram (Green region), which cause noise-like artifacts in the homogenous regions of image with a histogram as shown in Fig. 3. The redistribution will push some bins over the clip limit again. (yellow-shaded region in the Fig. 3)

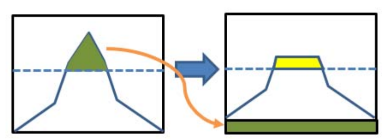
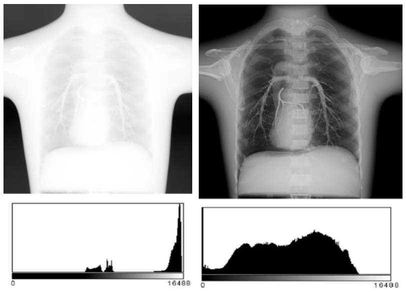


Fig. 3: Limits the amplification of histogram by clipping the histogram (Above dashed line)

The process of CLAHE consists two steps. Firstly, the image has to be divided into several non-overlapping regions of almost equal sizes. Secondly, the histogram of each region is calculated. Then, a clip limit for clipping histograms is obtained. Next, each histogram is redistributed in such a way that its height does not go beyond the clip limit. The clip limit is obtained by β which can be described in the form as follows:

$$\beta = \frac{MN}{L}\left(1 + \frac{\alpha}{100}\left(s_{max} - 1\right)\right) \tag{2}$$

where β is the clip limit, $M \times N$ is number of pixels in each region, L is the number of grayscales, α is a clip factor (0-100), and S_{max} is the maximum allowable slope. From equation (2), if α=0, then the clip limit = $\frac{MN}{L}$. However, S_{max} should set to four for still X-ray images.



(a) Original Image (b) Enhanced Image

Fig. 4: Results of the N-CLAHE method

3. EXPERIMENTAL RESULTS

The proposed method was tested using a survey phantom as shown in Figs.5 and a chest phantom as shown in Figs. 6.

On i7-CPU, CPU 2.0 GHz, using Java programming language, the computational time of the proposed algorithm took approximately less than two seconds. The raw X-ray images were obtained from a 17in$\times$17in a-Si TFT flat panel detector (Xmaru1717 by Rayence, South Korea) to capture 2D original raw data. The proposed method was compared with three different methods and compared their results with HE, USM and CLAHE. The performance of our enhancement algorithms was conventionally measured in term of high contrast resolution, low contrast detectability, expodure density variation for a survey phantom.

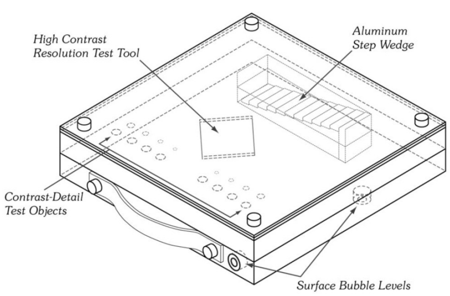


Fig. 5: A radiographic survey phantom (Gammex 170NJ)

Image quality assessment was first evaluated by a radiographic survey phantom (Gammex 170NJ) as shown in Fig.5. The high contrast resolution part contains different line pairs between 0.60 lp/mm to 10.00 lp/mm, i.e., the higher line pair value, the better high contrast resolution. The low contrast detectability part contains eight holes of 0.375 in diameter with the depths of 0.006 to 0.068 in, i.e., the smaller depth value, the higher low contrast detectability. Moreover, there are 11 different of aluminium step wedge to distinguish different shades of gray values for measurement and analysis of X-ray beam quality. Table 1 shows image quality assessment of a radiographic survey phantom (Gammex 170NJ). N-CLAHE

Table 1: Image quality assessment with a radiographic survey Phantom

Methods	HE	USM	CLAHE	N-CLAHE
High Contrast Resolution (lp/mm)	2.8	2.8	2.8	3.1
Low Contrast Resolution (in) @0.375(in)	0.035	0.025	0.025	0.025
Aluminum Step Wedge (Steps)	11	11	11	11

provided the high contrast resolution of 3.1 lp/mm, low contrast detectability of 0.025 in and visibility of all aluminium steps.

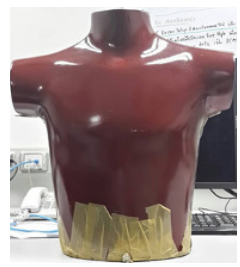
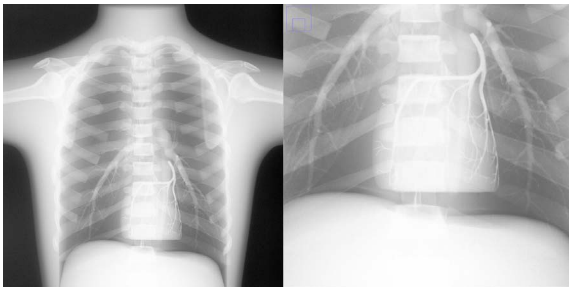


Fig. 6: A radiographic chest phantom (RS-315)

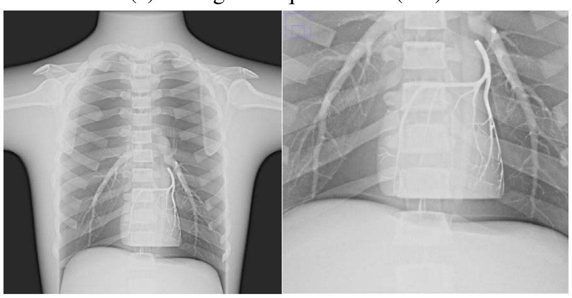
Visual assessment was evaluated by a radiographic chest phantom (Radiology Support Devices: RS-315) as shown Fig. 6. This phantom imitates the structure of heart, lungs, airways, blood vessels and spine. The visual results of HE, unsharp masking (USM), CLAHE and N-CLAHE algorithms using the chest phantom are shown in Fig. 7. The image from N-CLAHE method looked better than that of CLAHE as anatomical structures became more prominent. Although USM improved image contrast, but USM may not be suitable for clinical assessment because the processed image looked artificial and some new artifacts were introduced in the image.

4. CONCLUSION

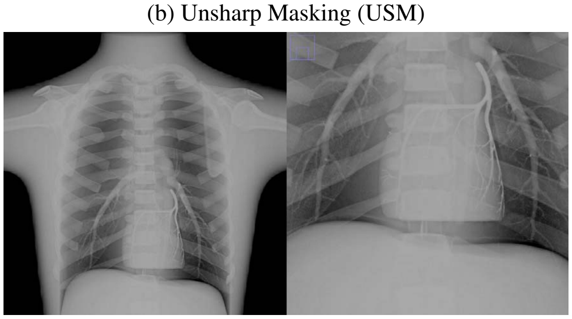
In this paper, we present an improved image enhancement algorithm on a digital X-ray image using N-CLAHE which consists of the log-normalization and CLAHE algorithms to preserve both structures and information within the image. We tested the performance of our proposed method using the radiographic survey phantom and the chest phantom, and compared its results with other three different methods. The result shows that N-CLAHE provided the best image quality when compared with other three methods including HE, USM and CLAHE. Thus the N-CLAHE method yielded the highest image quality among the other methods tested especially the high contrast resolution. Therefore, our proposed enhancement method can greatly help to visualize anatomical structures around the chest and lung area in 2D X-ray images for screening and diagnosis.



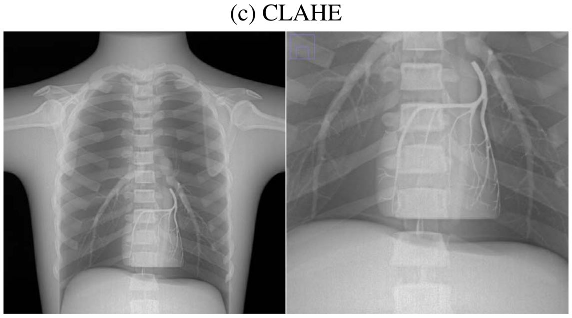
(a) Histogram Equalization (HE)



(b) Unsharp Masking (USM)



(c) CLAHE



(d) Normalization and CLAHE (N-CLAHE)

Fig. 7: Visual assessment the quality of chest phantom images

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