Employing a Suitable Contrast Enhancement Technique as a Pre-Restoration Adjustment Phase for Computed Tomography Medical Images

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Abstract

Improving the contrast of computed tomography medical images is an essential issue since most of these images suffer from the low contrast phenomenon. This study confirms that adjusting the contrast of degraded CT images before beginning the restoration process is highly desired. A comparison between seven famous techniques was conducted likewise to choose the best method among the different popular contrast enhancement methods. Then, experiments were performed to prove that adjusting the contrast before restoring CT images would lead to better restoration results. Finally, a discussion and a conclusion are provided to highlight the important issues of this paper.

Keywords: *Computed Tomography (CT) images, Contrast Limited Adaptive Histogram Equalization (CLAHE), CT contrast adjustment, CT contrast enhancement, CT degradations*

1. Introduction

In the medical field, CT systems are one of the essential implements to diagnose different types of diseases [7]. Still, every imaging device produces a degraded version of the original view it captures [14]. In case of computed tomography imaging systems, the captured images suffer from different categories of degradations such as noise [1], blur [2] and contrast imperfections [3]. The types of these degradations that spoil the CT images in an image level namely are: additive white Gaussian noise [4], Gaussian blur [5] and low contrast artifact [6]. Different causes participated to result faulty contrast levels in CT images such as varying display devices, acquisition methods, transmission storage and restoration and enhancement algorithms [3, 8]. In order to improve the quality and the visual appearance of CT images, two types of procedures are usually used, namely are: image restoration and image enhancement. Image restoration algorithms handle the issue of reducing the blur and noise amounts in the processed image. Likewise, image enhancement techniques handle the contrast enhancement and adjustment issues. Adjusting the contrast of CT images before performing the restoration procedures is and important matter, especially when the images are degraded by Gaussian noise. Since the noisy pixels are represented as white pixels in the CT image, the low contrast of the image would affect the performance of the denoising algorithms which may lead to misidentify the unwanted components of the image that must be removed and the denoising process would have major errors. In case of blur, trying to deblur CT images that own a low contrast may lead to miscalculating the correct amount of sharpening or the number of iterations needed due to the poor visual representation of the CT image. Moreover, contrast imperfection may lead to faulty diagnosis because much important information in the CT image is hidden or miss presented. Therefore, adjusting the contrast prior to the restoration operation should be concerned, and a reliable algorithm should be employed for that purpose.

2. Comparison

In this section, two naturally degraded images were chosen. Seven methods were selected for the comparison. Likewise, the results are displayed in the subsequent Figures 1 and 2.

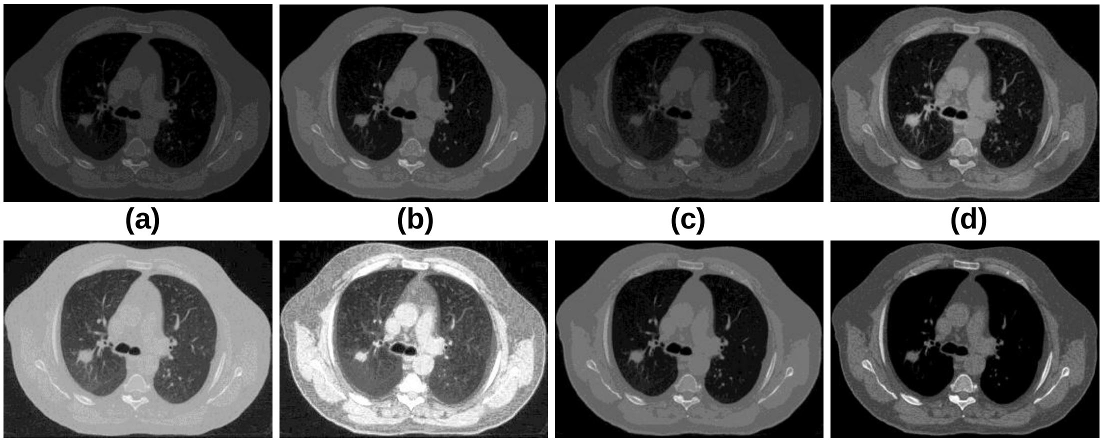


Figure 1. Images from (a) to (h): a) Low contrast CT image; Processed by: b) Adaptive contrast enhancement; c) Brightness preserving dynamic fuzzy histogram equalization; d) Contrast limited adaptive histogram equalization; e) Fourier domain based enhancement; f) Traditional histogram equalization; g) Normalization; h) sigmoid function.

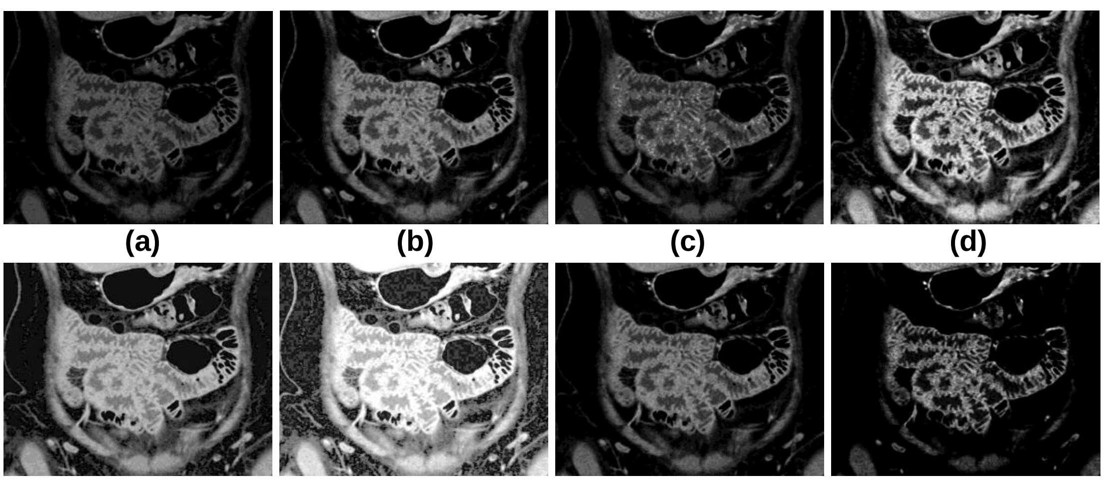


Figure 2. Images from (a) to (h): a) Low contrast CT image; Processed by: b) Adaptive contrast enhancement; c) Brightness preserving dynamic fuzzy histogram equalization; d) Contrast limited adaptive histogram equalization; e) Fourier domain based enhancement; f) Traditional histogram equalization; g) Normalization; h) sigmoid function.

Depending on the obtained results from the comparison, the contrast limited adaptive histogram equalization produced the best results in adjusting the contrast of the processed CT images. As shown in Figure 1.d, the processed image is showing clearly the bone and tissue components where the other methods fail to accomplish that purpose. Therefore, the contrast limited adaptive histogram equalization was chosen to be the pre-restoration adjustment method that would be employed in this paper and for that purpose, will be further elaborated in the succeeding section.

3. The Contrast Limited Adaptive Histogram Equalization

Different algorithms for contrast processing exist nowadays; the authors selected the Contrast Limited Adaptive Histogram Equalization (CLAHE) algorithm due to its robustness and reliability to process CT medical images. The authors tested this algorithm on more than fifty CT images, and the outcome was promising. Another reason that led to the selection of this algorithm is that its flexibility for improvement since many enhancements was applied by different researchers to this algorithm. The CLAHE technique employs the histogram equalization to a contextual area where, every pixel in the degraded image is in its center. Then the original histogram is clipped; then the clipped pixels are reallocated to every gray level. The newly produced histogram differs from the normal histogram, due to the limitation of the intensity for every pixel to manually choose the maximum value [12]. Typically, the CLAHE have six stages to achieve its desired purpose. The steps can be explained as the following [12]:

Stage 1: Separate the degraded image into many non-overlapping contextual areas where, each area has the size M×N.

Stage 2: Compute the histogram for every contextual area.

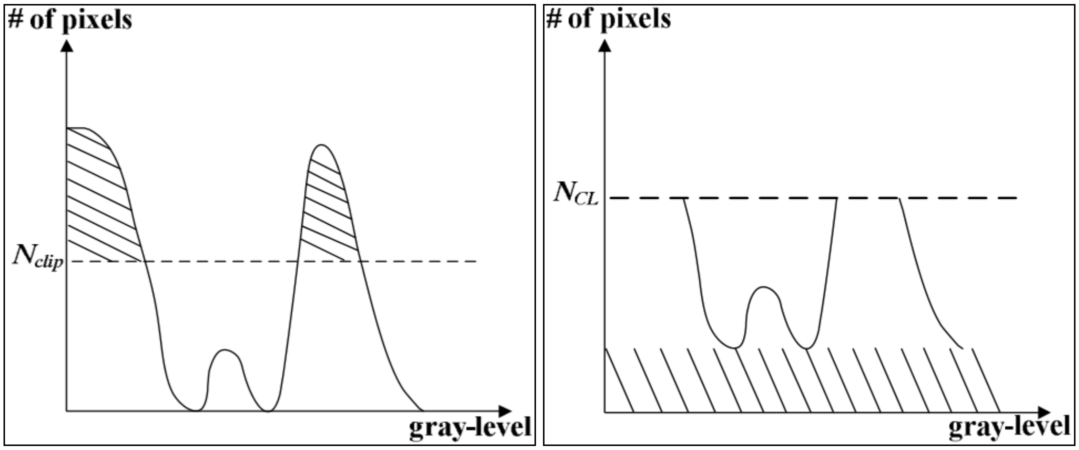
Stage 3: Clip the histograms. This process starts in the contextual area where, the number of pixels is similarly assigned to every gray level. The average number of pixels in every gray level can be calculated using the following equation:

$$N_{aver} = \frac{N_{CR\text{-}Xp} \times N_{CR\text{-}Yp}}{N_{gray}}$$

Where, (N_{aver}) is the average number of pixels; (N_{gray}) is the number of the gray levels in the contextual area; ($N_{CR\text{-}Xp}$) is the number of pixels in the x dimension of the contextual area; ($N_{CR\text{-}Yp}$) is the number of pixels in the y dimension of the contextual area. Depending on the previous equation, the actual clip-limit (N_{CL}) can be computed using the subsequent equation:

$$N_{CL} = N_{clip} \times N_{aver}$$

Where, (N_{clip}) is the highest multiple of average pixels in every gray level of the contextual area.



(a) (b)

Figure 3. Images from Left to Right: a) Original Histogram; b) Clipped Histogram

The pixels would be clipped in the original histogram if the number of pixels is more than (N_{clip}). The value $N_{\sum clip}$ is the overall number of clipped pixels as illustrated in Figure 3. The number of pixels that are assigned equally into every gray level can be calculated using the following equation:

$$N_{acp} = \frac{N_{\sum clip}}{N_{gray}}$$

Depending on the previous formula, the contrast limited histogram of the contextual area is computed using the subsequent rules:

$$if\ H_{CR}(i) > N_{CL} \quad H_{NCR}(i) = N_{CL}$$

$$Else\ if\ H_{CR}(i) + N_{acp} \geq N_{CL}, \quad H_{NCR}(i) = N_{CL};$$

$$Else\ H_{NCR}(i) = H_{CR}(i) + N_{acp}$$

Where, $H_{CR}(i)$ is the number of pixels in every gray level of the contextual area , and (i) is the number of gray level. After that, the residual number of clipped pixels defined as (N_{LP}), and the distributed pixels (S) can be found suing the following equation:

$$S = \frac{N_{gray}}{N_{LP}}$$

Stage 4: Process every grayscale histogram which has limited contrast in every contextual area by employing the histogram equalization.

Stage 5: Consider the sample points as the points that are located in the center of the contextual area.

Stage 6: The outcome mapping at any pixel is interpolated from the sample mappings at the four neighboring sample-grid pixels.

4. Experimental Results

The experiment was divided into two phases. The first phase handles the deblurring of CT images before and after adjusting the contrast. The second phase concerns the denoising of CT images before and after adjusting the contrast. The images employed in this experiment are collected from the internet and scientific journals. The blurry image was obtained from [9]. The noisy image was obtained from [3]. Both images are 8 bit grayscale images. The experiments were conducted using Matlab R2008. For the deblurring purpose, the Richardson-Lucy iterative algorithm was used with a Gaussian point spread function (PSF) because CT images are blurred by Gaussian blur [10]. For the denoising purpose, the phase preserving algorithm was employed to eliminate the additive white Gaussian noise [11, 13]. Figure 4 illustrates the deblurring results. Figure 5 displays the denoising outcomes.

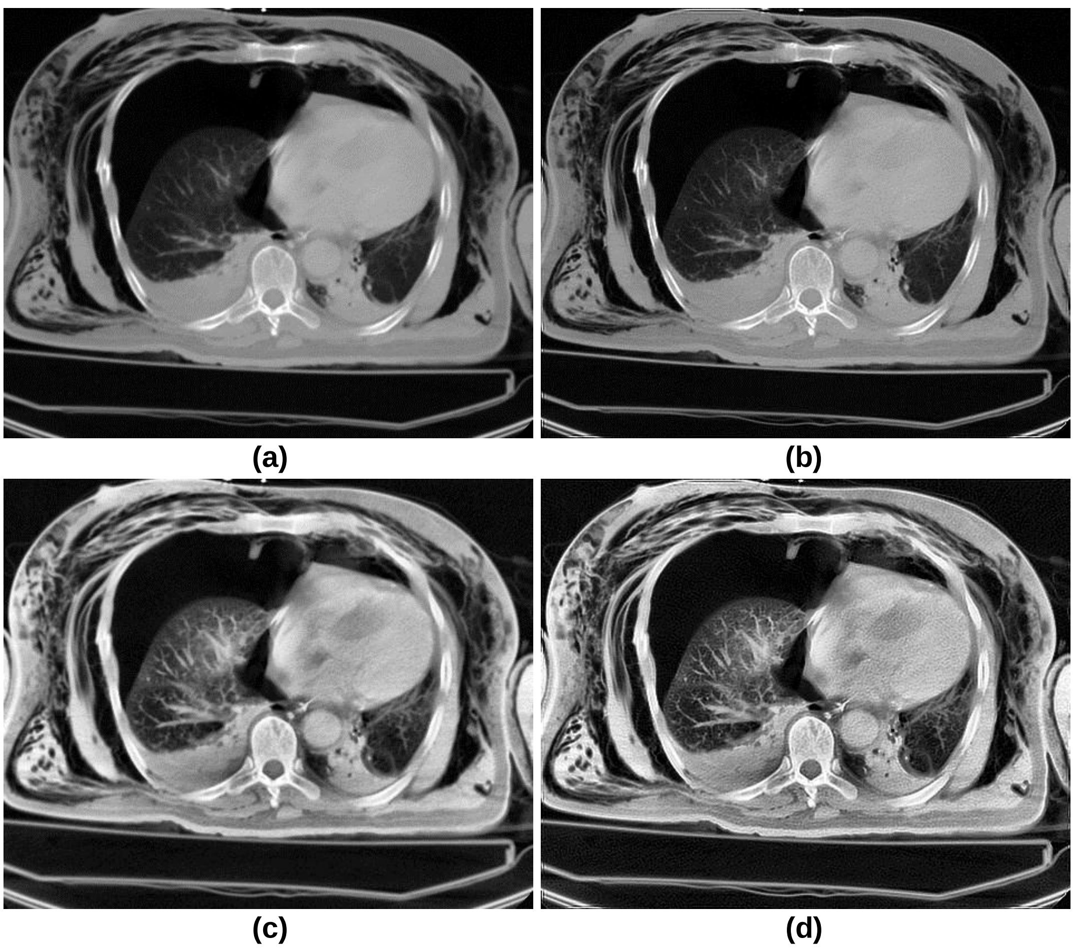


Figure 4. Images from (a) to (d): a) Blurry CT Image; b) Deblurred by the Richardson-Lucy Algorithm; c) Image (a) Enhanced by CLAHE; d) Enhanced Image Deblurred by the Richardson-Lucy Algorithm

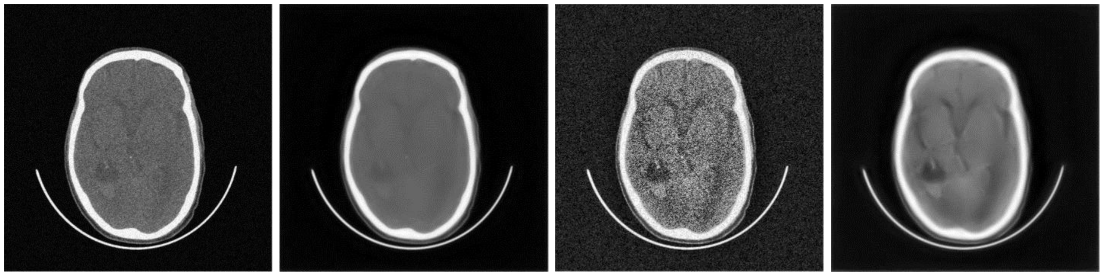


Figure 5. Images from Left to Right: a) Noisy CT Image; b) Denoised by the Phase Preserving Algorithm; c) Image (a) Enhanced by CLAHE; d) Enhanced Image Denoised by the Phase Preserving Algorithm

5. Discussion

As observed in the above Figures 4 and 5, the use of a pre-restoration contrast adjustment technique such as CLAHE gave very promising results when the degraded CT images were restored using reliable methods. In Figure 4, the image that was restored without contrast adjustment shows less visual details than the one that is contrast adjusted, and it's a similar situation in the case of denoising as in Figure 5. Likewise, the restored images conserved more visual features. Using this proven fact, a determination is formed that the need for adjusting the contrast as a pre-restoration procedure is an important matter and it should be highly concerned because the results of the restoration depend on that procedure.

6. Conclusion

Many methods were used to enhance the contrast of CT images. Most of these methods focus on low-contrast images. This study provides a good method to adjust the contrast by comparing different famous method and selecting the right one. Furthermore, experiments were conducted to prove the effect of contrast adjustment when restoring degraded CT images. Moreover, this study provides good evidence about the necessity of employing a contrast adjustment technique before restoring degraded CT images. The conducted experiments show that various features from the affected CT images could be revealed and preserved when adjusting their contrast before the restoration process starts using a reliable contrast enhancement method. Providing a novel specialized algorithm to meet that purpose is highly desired to get better restoration results.

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