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Radiographic Image Enhancement Using Hybrid Algorithm

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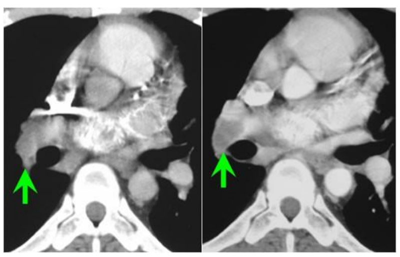
Graphical abstract



Abstract

Radiographic image quality is important in the medical field since it can increase the visibility of anatomical structures and even improve the medical diagnosis. Because the image quality depends on contrast, noise, and spatial resolution, images with low contrast, a lot of noises, or low resolution will decrease image quality, leading to an incorrect diagnosis. Therefore, radiographic images should be enhanced to facilitate medical expertise in making correct diagnosis. In this paper, radiographic images are enhanced by hybrid algorithms based on the idea of combining three image processing techniques: Contrast Limited Adaptive Histogram Equalization for enhancing image contrast, Median Filter for removing noises, and Unsharp Masking for increasing spatial resolution. Two series of medical images consisting of 20 x-ray images and 20 computed radiography images are enhanced with this method. Peak Signal to Noise Ratio (PSNR) and image contrast are computed in order to measure image quality. The results indicate that the enhanced images have better PSNR.

Keywords: Image enhancement, radiographic images, contrast, hybrid algorithm

1.0 INTRODUCTION

Digital radiographic image is a shadow projection on digital x-ray sensors of high energy electromagnetic ray that passes through human organs. The intensity of the ray will decrease when it passes objects due to absorption of the ray. High dense objects such as bones will be displayed in white or light gray while low dense objects such as lungs can be seen in black or dark gray on the display. Digital radiography performs faster than a regular radiography because it bypasses chemical processing. However, it can neither distinguish overlapping organs such as liver and pancreas nor distinguish small nearby objects very effectively. Therefore, these images must be further enhanced to overcome those limitations.

The digital images can be further enhanced so that the internal organs are clearly visible to the naked eyes while also meet desirable contrast. The enhanced images will later be inspected by the medical experts in order to diagnose symptoms and diseases. Therefore, high quality enhanced images will lead to accurate diagnosis. Image quality can be measured by three factors; light contrast between objects and background, the quantity of noises, and spatial resolution. These three factors will be evaluated to determine the effectiveness of our methods.

This paper will combine different methods consisting of median filtering, unsharp masking, and contrast-limited adaptive histogram in order to enhance chest x-ray images which will be used in medical diagnosis. This hybrid algorithms produce images with higher PSNR than the original images.

2.0 RELATED WORKS

There are several enhancement techniques that can be applied to various type of medical images. Blurred medical images can be enhanced by spatial filtering technique [2]. Images with several small organs can be emphasized via fusion technique proposed in [8]. The fusion technique includes contrast adjustment for distinguishing small nearby objects, which will be exploited in this paper. Denoising and smoothing are also important techniques in reducing the abnormal gradient of the pixels. Bhausaheb [1] uses different filters such as median filter, average filter and adaptive filter to filter out speckle noises in Magnetic Resonance Imaging (MRI). It is shown that the choice of filters depend on the type of noises.

Chest x-ray images can be enhanced by a combined method of histogram equalization and unsharp mask algorithms. If the patient has lung-related disease, the combined method is preferred by radiography experts [5]. Piched [9] analyses the effectiveness of contrast limited histogram equalization, contrast stretching, histogram equalization, and mathematical morphology on chromosome G-band images. Histogram equalization is suitable for enhancing chromosome images while contrast limited histogram equalization is suitable for image segmentation. Pizer [6] applies contrast-limited adaptive histogram equalization on computed tomography images of lungs and internal tissues. The use of multiprocessor AHE Machine speeds up the enhancement process which is favorited by clinic works.

It is evident that each method can enhance an image in a certain way through pixel-based computation. This paper will combine different methods such as median filtering, unsharp masking and contrast-limited adaptive histogram in order to enhance chest x-ray images which will be used in medical diagnosis. This hybrid algorithms will be evaluated by image quality assessment using PSNR and light contrast.

3.0 METHODOLOGY

3.1 Data Acquisition

Images in this paper are divided into two sets totaling 40 images. The first set consists of 20 chest x-ray images. The resolution of the images is 653 x 653 and the image depth is 8 bits. Images are further divided into blurred images and images manually enhanced by the Department of Radiology. The second set of images consists of 20 CT scan images of internal organ cross section, which are all blurred. The resolution of the images is 512 x 512. Because the original file format is a 16-bit Digital Imaging and Communications in Medicine (DICOM), the image size is considered large and requires longer computational time and larger storage space. To avoid excessive computation, the images are converted to an 8-bit Tagged Image File Format (TIFF). Sample images are shown in Figure 1. We will refer to both image sets as Set 1 and Set 2 respectively throughout the section.

3.2 Hybrid Algorithms

Authors of [5] experimented with a combined algorithm of histogram equalization and unsharp masking to enhance regular radiographic images, which reduces the need to retake radiographic images and cost while maintaining accuracy of diagnosis. Our hybrid method will be based on their concept which consists of median filtering for noise reduction, unsharp masking for image sharpening, and adaptive histogram equalization for contrast enhancement. For adaptive histogram equalization, both uniform variant and exponential variant will be experimented. The hybrid method will be divided into 2 separate procedures, one for each data set, though both procedures are very similar.

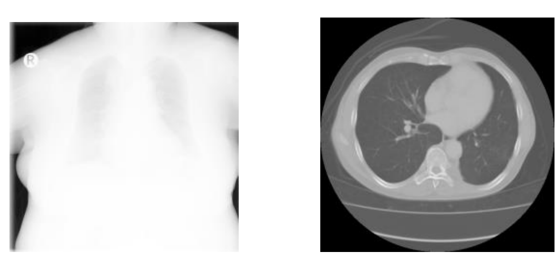
Image enhancement for Set 1 images is as follows:

- Convert both blurred images and manually enhanced images in Set 1 to grayscale images.
- Apply 3 x 3 median filter to reduce noise.
- Increase contrast with Contrast-Limited Adaptive Histogram Equalization (CLAHE). For uniform equalization, NBin is 256. For exponential equalization, NBin is 512.
- Apply unsharp mask with radius of 0.1 to obtain the final enhanced image.

Image enhancement for Set 2 images is as follows:

- Convert all images in Set 2 into grayscale images.
- Apply 3 x 3 median filter to reduce noise.
- Apply unsharp mask with radius of 0.1.

Increase contrast with CLAHE with NBin of 256 and 512 in separate runs to get the final images.



(a) (b)

Figure 1 Sample images of the data set. (a) Chest x-ray image from Set 1 (b) CT scan image from Set 2

3.3 Image Quality Assessments

1) Quantitative Measurement: Contrast is defined as a difference in luminance between objects and background. Contrast is affected by the quality of x-ray sensors and errors in image acquisition process. Objects are more distinguishable in higher contrast images as shown in Figure 2 Average contrast over the entire image set will be used for evaluation.

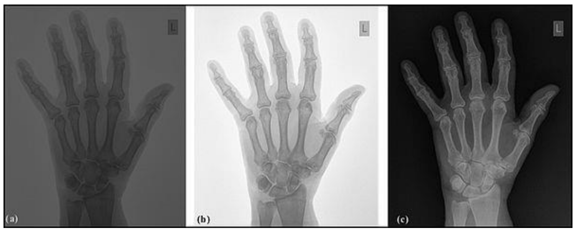


Figure 2 Rediographic Image of Wrist. (left) Low constrast image (center) High contrast image (right) An inverted grayscale [3]

Noise is often found in radiographic images, which reduces the quality of the images. Possible forms of noise are quantum noise, electronic noise, noise induced from round-off errors, structural noise and artifactual noise such as streak from patient's movement, ring from ray detector, and shade from insufficient ray as shown in Figure 3. To measure the noise, we will look at the ratio between the maximum signal power and noise power as shown in (1) and (2):

$$\mathrm{PSNR} = 20\log_{10}\left(\frac{\mathrm{MAX}}{\mathrm{RMSE}}\right) \tag{1}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum\left(\mathrm{O(i,j)} - \mathrm{E(i,j)}\right)^2}{\mathrm{d}}} \tag{2}$$

where MAX is the maximum pixel value of an image, O(i, j) is pixel value of an original image at coordinates (i, j), E(i, j) is the pixel value of an enhanced image at the same coordinates, and d is the total number of pixels of an image.

2) Quantitative Measurement: Spatial resolution affects ability to distinguish objects in an image. It is determined by the number of pixels per area. Small objects in low resolution images may occupy one pixel making it become uninterpretable while they span several pixels in higher resolution images. Image resolution depends on spatial frequency which is the sampling rate. If the sampling rate is high, the image will also have high resolution, resulting in high detailed images as shown in Figure 4. In our case, we preserve the original resolution and only reduce the dynamic range by one degree. Furthermore, the enhanced images will be inspected by 3 medical experts who will judge whether images enhanced by our method are better than those manually enhanced by the department of radiology without knowing which images come from which source. The satisfactory score is between one and five for each inspected image.

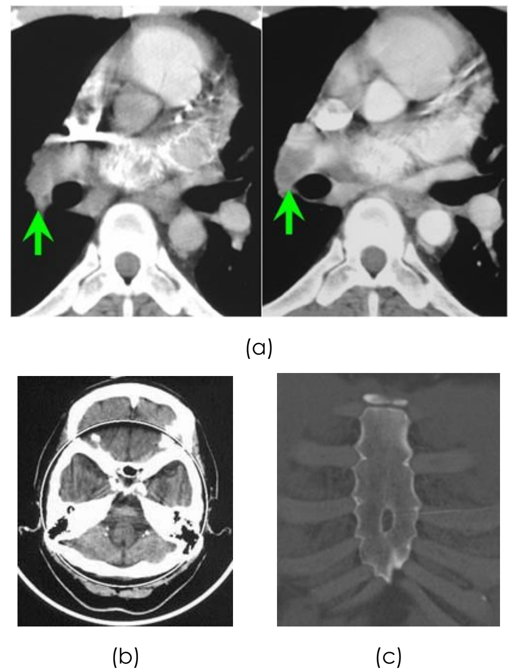


Figure 3 Type of noise in CT images. (a) Streak from patient's movement (b) Ring from ray detector (c) Shade from insufficient ray [7]

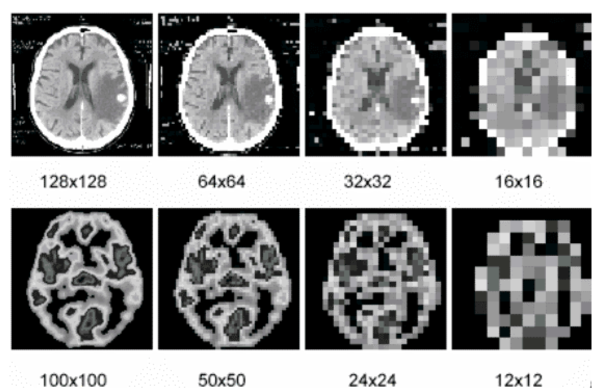


Figure 4 Different spaial resolution of CT images of brain [4]

4.0 EXPERIMENTAL RESULTS

4.1 Results for Set 1 Images

Our hybrid algorithm is applied to the whole image as oppose to parts of the image. However, we found that the lung and its arteries in the enhanced image are sharper than those in the manually enhanced image while trachea area bears no difference as shown in Figure 5. For quantitative measurement, our hybrid method produces images with higher contrast than the manually enhanced image as shown in Table 1. Furthermore, Uniform Normal CLAHE with NBin of 256 gives the best PSNR value as shown in Table 2. The satisfactory score from the experts is 73% for manually enhanced images and 70% for our hybrid method.

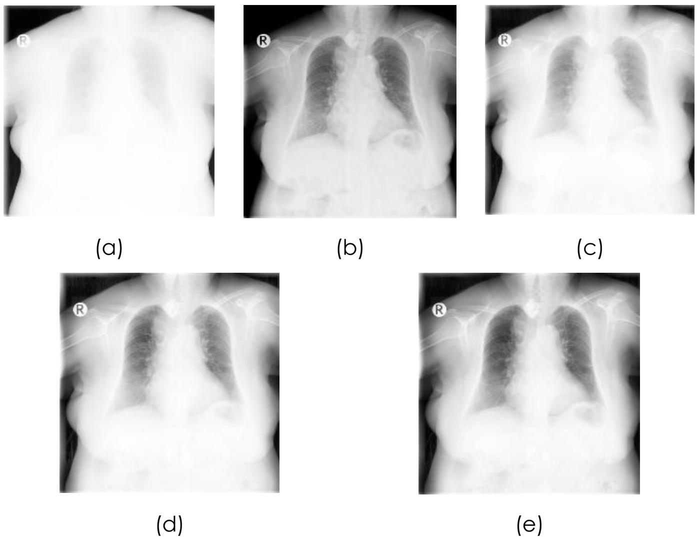


Figure 5 Comparison of the original chest x-ray image in Set 1 and enhanced images via different parameters. (a) Original image (b) Manually enhanced image from the department of radiology (c) Uniform Normal CLAHE with NBin of 256 (d) Uniform Normal CLAHE with NBin of 512 (e) Exponential CLAHE with NBin of 512

4.2 Results for Set 2 Images

Our hybrid method produces sharper images compared to the original as shown in Figure 6. The internal organs are more visible especially in the case of Uniform Normal CLAHE with NBin of 512. Table 3 shows the contrast of the enhanced images. The contrast is on par with original image, meaning that the contrast is within an acceptable range. The satisfactory score from the experts is 74%.

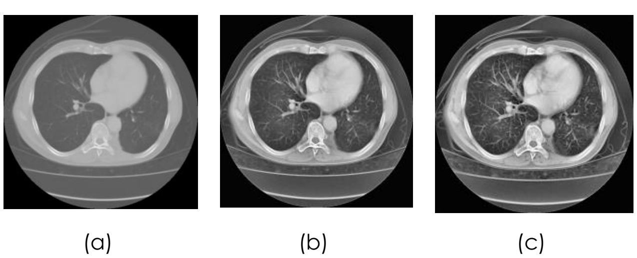


Figure 6 Comparison of the original cross section image in Set 2 and enhanced images via different parameters. (a) Original image (b) Uniform Normal CLAHE with NBin of 256 (c) Uniform Normal CLAHE with NBin of 512

Table 1 Contrast of set 1 images

Number	Manual Enhanced	Hybrid Method		
		Normal CLAHE		Expo CLAHE
		NBin 256	*NBin 512*	*NBin 512*
1	156.42	211.38	201.66	186.88
2	147.03	190.48	178.53	160.71
3	119.69	152.52	146.08	126.83
4	129.10	166.84	157.85	139.77
5	145.79	204.57	191.98	175.60
6	133.42	163.84	152.43	133.07
7	158.75	206.03	193.84	176.50
8	146.36	194.77	184.15	167.47
9	133.72	163.41	152.04	132.99
10	135.98	166.89	153.80	134.48
11	145.26	195.17	184.79	167.96
12	176.92	219.60	206.27	189.44
13	150.25	192.06	178.30	159.82
14	144.81	188.01	175.03	156.59
15	127.28	144.46	138.08	118.72
16	128.38	157.82	150.71	133.04
17	136.15	170.22	157.19	137.67
18	147.56	192.82	182.86	166.20
19	157.16	200.73	186.38	167.66
20	170.07	226.14	216.69	203.48
Average	144.50	185.39	174.38	156.74

Table 2 PSNR of set 1 images

Number	Manual Enhanced	Hybrid Method		
		Normal CLAHE		Expo CLAHE
		NBin 256	*NBin 512*	*NBin 512*
1	58.00	68.19	64.31	61.41
2	59.29	67.55	63.17	60.47
3	61.15	66.36	62.83	60.63
4	60.61	67.55	63.54	60.95
5	57.66	67.46	62.87	60.03
6	60.65	65.11	61.74	59.45
7	58.75	67.88	63.61	60.68
8	59.01	68.40	63.98	61.10
9	60.91	65.36	61.88	59.56
10	60.30	65.03	61.40	59.10
11	58.73	68.44	64.06	61.16
12	58.76	67.60	63.27	60.41
13	58.99	66.17	62.06	59.51
14	59.05	66.50	62.25	59.69
15	63.25	64.97	62.25	60.33
16	61.33	65.62	62.64	60.55
17	60.57	66.41	62.20	59.71
18	59.19	68.19	64.00	61.17
19	58.97	67.11	62.69	59.83
20	57.99	70.98	66.02	62.77
Average	59.66	67.04	63.06	60.44

5.0 CONCLUSIONS

Our hybrid method produces better quality images than the original images. The detail within the images is emphasized especially in the result from Set 2 images whose internal organs are nicely distinguishable. For Set 1 images, Uniform Normal CLAHE gives a higher PSNR than the manually enhanced method but the contrast is still low. For Set 2 images, the contrast of the hybrid method does not differ from that of the originals but the enhanced images are visually better than the originals. Set 1 images have higher initial contrast than the It is important to note that lower NBin value will produce images with higher contrast while Normal Uniform CLAHE produces images with higher contrast than Exponential CLAHE. According to the satisfactory score of 70% and 71% for Set 1 and Set 2 respectively which are considered good scores, our hybrid method will be useful in assisting medical diagnosis.

Table 3 Contrast of set 2 images

Number	Original	Hybrid Method	
		Normal CLAHE	
		NBin 256	***NBin 512***
1	72.48	77.65	78.86
2	96.29	91.59	91.70
3	91.22	88.28	88.08
4	87.18	87.05	87.54
5	99.98	96.58	96.51
6	89.77	90.23	90.58
7	94.57	95.94	96.04
8	87.49	87.43	87.96
9	98.48	96.97	96.94
10	82.51	83.32	84.42
11	88.80	86.49	86.95
12	94.59	90.28	90.20
13	96.65	91.35	91.05
14	86.35	87.56	88.78
15	54.25	63.13	65.95
16	92.61	93.96	94.02
17	91.49	88.64	89.11
18	90.92	88.38	88.34
19	91.24	87.77	88.09
20	97.36	91.60	92.25
Average	89.21	88.21	88.67

6.0 FUTURE WORKS

Instead of whole image enhancement, image segmentation can used at the preprocessing step to specify the region of interest so that region can be specifically enhanced. It can also be used at post-processing step to segment out the internal organ of interest in order to further emphasize each organ. Color segmentation can improve the sharpness of the original images by applying certain enhancement to a specific color range. A typical edge detection can detect the separation of internal organs so that separation line can be emphasized as oppose to unsharp masking. More measurement can be introduced to ensure the quality of the assessment such as human visual based measurement.

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