Exploiting Hybrid Methods for Enhancing Digital X-Ray Images

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Abstract: *The principle objective of image enhancement is to process an image so that the result is more suitable than the original image for a specific application. This paper presents a novel hybrid method for enhancing digital X-Ray radiograph images by seeking optimal spatial and frequency domain image enhancement combinations. The selected methods from the spatial domain include: negative transform, histogram equalization and power-law transform. Selected enhancement methods from the frequency domain include: gaussian low and high pass filters and butterworth low and high pass filters. Over 80 possible combinations have been tested, where some of the combinations have yielded in an optimal enhancement compared to the original image, according to radiologist subjective assessments. Medically, the proposed methods have clarified the vascular impression in hilar regions in regular X-ray images. This can help radiologists in diagnosing vascular pathology, such as pulmonary embolism in case of thrombus that has been logged in pulmonary trunk, which will appear as a filling defect. The proposed method resulted in more detailed images hence, giving radiologists additional information about thoracic cage details including clavicles, ribs, and costochondral junction.*

Keywords: *X-Ray, radiography, image enhancement, spatial domain, frequency domain.*

Received June 19, 2010; accepted March 1, 2011

1. Introduction

Image processing has received significant attention in the last few years. This is due to its broad range of applications including astronomy, medicine, industrial robotics, and remote sensing by satellites [17]. Among many other vital image processing operations is image enhancement which is one of the pre-processing steps that can be applied on an image before studying the details. Image enhancement refers to any technique that improves or modifies the digital image so that the resulting image is more suitable than the original for a specific application. Mainly, image enhancement includes but not limited to intensity and contrast manipulation, noise reduction, background removal, edges sharpening, and filtering.

An X-ray (radiograph) is one of the oldest and most commonly used medical tests that help physicians diagnose and treat medical conditions. Radiography involves exposing a part of the body to a small dose of ionizing radiation to produce pictures of the inside of the body [8]. But degradation of digital X-ray medical image such as low contrast and blurring during radiographic imaging, caused by the complexity of the body tissue and by the effects of X-ray scattering and electrical noise [8], can negatively influence the subsequent analysis and diagnosis carried out by the radiologists. Hence, it is crucial to enhance the details of X-ray medical images in order to improve their visual quality, and aid radiologists in making more informed diagnosis. Image enhancement tasks are usually divided into two broad categories: spatial domain methods and frequency domain methods. Spatial domain methods are procedures that operate directly on the aggregate of pixels composing an image. While, frequency domain methods are procedures that manipulate information in the frequency domain based on the frequency characteristics of the image.

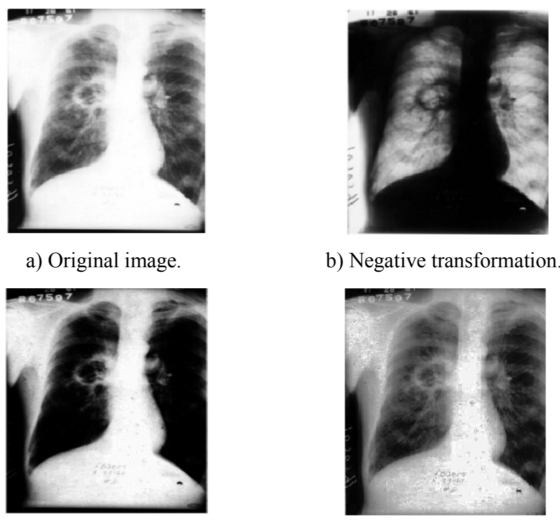
This paper investigates multiple combinations of image enhancement methods from both domains, in order to enhance the appearance of X-ray images which will assist radiologists in diagnosing certain diseases. The content of this paper is structured as follows. Section 2 presents enhancement methods in the spatial domain. Section 3 presents enhancement methods in the frequency domain. Section 4 discusses hybrid methods, where methods from both sides are combined in order to enhance the appearance of X-ray images. Section 5 introduces the experimental results and provides intensive evaluation for the proposed system. Finally, section 6 concludes the paper with an insight into the future direction of this research.

2. Image Enhancement in the Spatial Domain

The notion of enhancing digital images in the spatial pixel domain is based on applying some mathematical filters on the image matrix. Enhancement methods in the spatial domain are broadly divided into three categories: point processing methods, histogram-based processing methods, and mask processing methods [9]. Point processing methods include the negative transformation, $s=(L-1)-r$, where r is the original image, L is the range of pixel intensity values in the original image, and s is the processed image. The negative transform is intended to highlight details in dark regions.

Power law transformation, given by $s=cr^y$, where c is a constant value, s is the processed image, r is the original image, and y is the power factor power law transformation is also used for gamma correction in CRT monitors. Different monitors do not have the same ability of displaying the same image with the same output colours and quality. Histogram processing intends to redistribute the intensity values equally amongst the whole image, while the mask processing enhancement techniques produce an enhanced image where each pixel value in the processed image is a result of a function applied on the original image. Figure 1 (a-d) shows the results of applying the spatial domain enhancement methods.

Based on the above standard methods for enhancing images in the spatial domain, Oktem and Egiazarian [16] proposed a method for modifying the histogram of an image to improve the visibility of small details in a medical X-Ray image, by taking a sample of the histogram of the image using a threshold value defined by the user. Cheng and Shi [3] proposed a multi-peak Generalized Histogram Equalization (GHE) which enhances gray-scale images based on their intensity histogram. Their results show that this method is applicable on images that have a narrow intensity range. Wanga and Wong [22] applied the contrast limited histogram equalization and adaptive wavelet thresholding to x-ray images in order to reduce defects and enhance the images visual perception.



a) Original image. b) Negative transformation.

c) Power-law transformation. d) Histogram equalized image.

Figure 1. Image enhancements using spatial domain methods, original image is courtesy of the medical image database, radiology teaching files [15].

3. Image Enhancement in the Frequency Domain

The purpose of the transform stage is to represent the image data in another form. The choice of transformation technique is governed by a number of criteria. Regardless of the chosen transformation method, data in the transform domain should be decomposed into separate components with minimal dependencies [12]. Any image transformation technique should be reversible and computationally tractable. Several transforms have been proposed for image and video compression and the most popular transforms fall into two categories: block-based and image-based transformations. Examples of the former include: singular value decomposition, the karhunen-loeve transform, and the Discrete Cosine Transform (DCT) [9]. Each of these block-based methods operates on blocks of N×N image or residual samples and therefore the image is processed in units of a block. Block transforms have low memory requirements but tend to suffer from artefacts at block edges 'blockiness'. Image-based transforms operate on an entire image. Examples of these transformations include Walsh Hadamard Transform, and the popular Discrete Wavelet Transform (DWT). Image transforms such as the DWT have been shown to out-perform block transforms for still image compression but they tend to have higher memory requirements. All transform types are in discrete mode, since the image is a set of discrete values [19]. In this research, the DCT is chosen as the transformation method. The enhancement process is designed to operate over N×N block sizes. The DCT operates on F, a block of N×N samples pixels and creates B, an N×N block of coefficients. The action of the DCT (and its inverse, the IDCT) can be described in terms of a transform matrix W see equation 1. The DCT of an N×N sample block is given by: $B=AFA^T$. And the Inverse DCT (IDCT) is given by: $F=A^TBA$, where F is a matrix of samples, B is a matrix of coefficients and A is an N×N transform matrix. The elements of A are:

$$A_{ij} = C_i Cos\left(\frac{(2j+1)i\pi}{2N}\right) \quad (1)$$

Where

$$C_i = \sqrt{\frac{1}{N}}(i=0),\; C_i = \sqrt{\frac{2}{N}}(i \geq 0)$$

Filtering in the frequency domain consists of the following steps:

- Multiplying the input image by $(-1)^{x+y}$ to centre the transform.
- Computing $F(u, v)$, using any of the transformation methods.
- Multiplying $F(u, v)$ by a filter function $H(u, v)$.
- Computing the inverse transformation of the result.

- Multiplying the result in by $(-1)^{x+y}$.

In signal processing, it is known that the signal is composed of a frequency spectrum. Low pass filters and high pass filters are used to show some details in the image while hiding other details. Low pass filters blur the image which leads to noise reduction, while high pass filters sharpen some image details, such as the edges [9]. In this research the types of filters that are used include:

- The Gaussian Low Pass Filter (GLPF) given by:

$$H(u,v) = -e^{-D(u,v)/2D_o^2} \tag{2}$$

- The Butterworth Low pass filter given by:

$$H(u,v) = \frac{1}{1+[d(u,v)/D_O]^{2n}} \tag{3}$$

- The Butterworth high pass filter given by:

$$H(u,v) = \frac{1}{1+[d(u,v)/D_O]^{2n}} \tag{4}$$

- The Gaussian high pass filter given by:

$$H(u,v) = -e^{-D^2(u,v)/2D_O^2} \tag{5}$$

where in the above equations 1, 2, 3, 4 and 5, $D(u, v)=[u-M/2)^2+(v-N/2)^2]^{1/2}$ and D_0 is the distance of the cut-off frequency from the origin. One way to establish a set of standard cut-off frequency Loci is to compute circles that enclose specified amounts of total image power P_T. This quantity is obtained by summing the components of the power spectrum at each point (u, v), for u=0, 1, 2, ... M-1 and v=0, 1, 2, ... N-1, that is:

$$P_T = \sum_{u=0}^{M-1}\sum_{v=0}^{N-1} P(u,v) \tag{6}$$

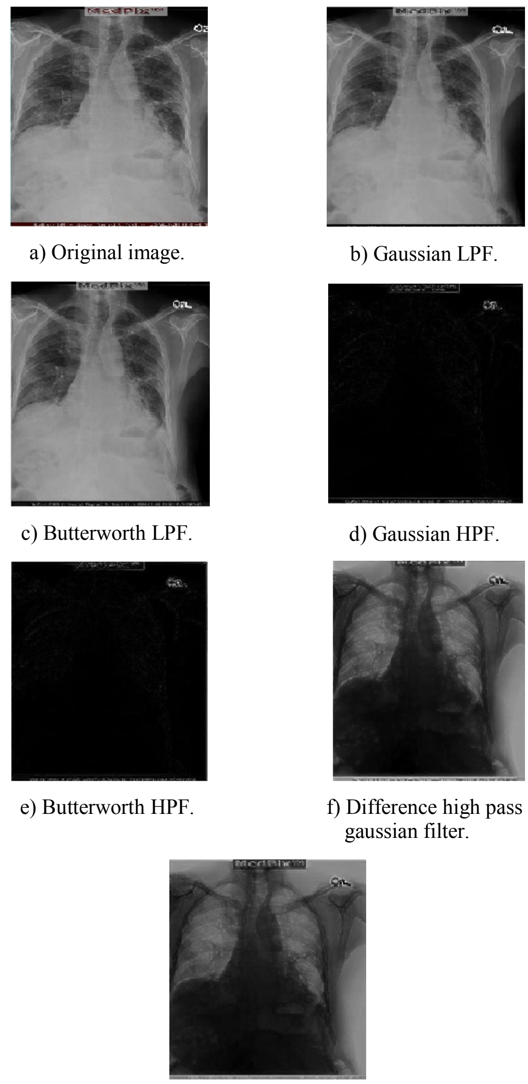
Where

$$P(u,v) = |F(u,v)|^2$$

The basic model for filtering in the frequency domain is given by the following equation:

$$G(u,v) = H(u,v)F(u,v) \tag{7}$$

where $H(u, v)$, and $F(u, v)$ are the requested filter and the Fourier transform of the image to be smoothed, respectively.The differences between the butterworth and gaussian filters is that the former is sharper than the latter, and the strength of the low and high pass filters reside in the shape of the curve or the plot of the function; this originates from the equation that formulates each of the functions. The high pass filters have a sharpening effect on the image, such that some of the image details are sharpened and emphasized, those details include areas where high frequency or great intensity variations exist such as edges or noise. On the other hand, low pass filters help in smoothing the sharp details in a given image. Figure 2 (a-g) illustrates the result of applying the frequency domain enhancement methods.



a) Original image. b) Gaussian LPF. c) Butterworth LPF. d) Gaussian HPF. e) Butterworth HPF. f) Difference high pass gaussian filter. g) difference high pass Butterworth filters.

Figure 2. Image enhancements using frequency domain methods, original image is courtesy of "medpix" the medical image database radiology teaching files [15].

In literature, there have been some studies which covered the use of the frequency domain filters, such as the approach proposed by Wong [23], who used a technique called the clustering filter. The clustering filter starts by providing a smoothed copy of the image, smoothing means not all useful signals are preserved and some details like dark or light spots are removed and edge corners are rounded. The second step is to subtract the smoothed image from the original image, and then compute the mean and variance of each pixel in the image resulted from subtraction. Generally, this technique produced a very good image quality while at the same time, the edges are preserved and any possible halos effects are avoided.

Zwirn and Akselrod [24] in their work proposed an enhancement method for echocardiography images. Such images suffer from noise and difficulty in interpretation. The research proposed a method called

Adaptive Brightness Transfer Function (ABTF) which is an improvement on a previously used method called Brightness Transfer Function (BTF). The proposed method segments the gray-level histogram for each region of the image.

Kim *et al*. [13] in their work proposed an enhancement method for fingerprint images which suffer from bad quality due to non-uniformity of ink or non-uniformity of the contrast on the captured image. The method is based on image normalization and gabor filter. The main addition of this research is suggesting a new method for selecting two important parameters that are used in the gabor filter.

Fanga *et al*. [7] in their work proposed an image enhancement method for smoothing details and preserving edges of an image based on nonlinear diffusion equation. Mean Curvature Motion (MCM) equation have been used to smooth details while the inverse heat diffusion equation was used to preserve edges. Results applied on a set of images showed promising results obtained by applying the proposed method, proved by the sharpened image details while edge preservation is taken in consideration.

4. Hybrid Enhancement Methods

A combination of spatial and frequency domain enhancement techniques is not rare but lack in literature. Hirani and Totsuka [10] in their work proposed an image enhancement technique used for enhancing old digital images and movies, which may contain scenes that are subject to some kind of noise. In their research, the authors introduced enhancement methods based on frequency and spatial domain information. Their proposed method is based on the concept of Projection On Convex Sets (POCS) for noise removal. The method searches for noisy pixels in order to replace them by pixels from the neighbourhood. The algorithm can handle images with varying intensities. Based on the authors comments results obtained using the proposed algorithm showed promising results in reconstructing images that have repeating patterns. The limitations of the proposed approach are that the contents of sample and repair sub images must be approximately translated versions of each other. If the prominent lines and texture in repair and sample sub images are rotated versions of each other then the algorithm will not work.

This research introduces a hybrid system for X-ray image enhancement in the frequency and spatial domains. The proposed method comprises two main steps for image enhancement; the first step is to apply a spatial domain method that fits the enhancement of X-ray images. The second step is to apply a frequency domain method on the resulted enhanced image from the first step.

5. Experiments

As indicated earlier, this research investigates the use of a proper combination of enhancement methods in both frequency and spatial domains for the purpose of enhancing X-ray images, a combination of the following spatial domain methods: negative, power-law, and histogram methods, in addition to the following frequency domain methods: gaussian low pass, low pas butterworth, high pass gaussian and high pass butterworth methods. This would yield in 12 combinations to be tested. Moreover, the authors have tested the combinations with different cut-off and power-law factors in order to test their efficiency more properly. The experiments have revealed in more than 80 possible combinations, which entirely covers the possibilities of the enhancement process. Tables 1, 2 and 3 illustrate all the covered combinations. Figure 3 presents a flowchart of the proposed system.

Table 1. Combining histogram equalization with frequency filters.

Histogram Combinations				
Frequency Filter	**GLPF**	**BLPF**	**GHPF**	**BHPF**
Cutoff Distances (Low-Pass Filter)	40	80	120	230
Cutoff Distances (High-Pass Filter)	40	80	120	NAN

Table 2. Combining negative transform with frequency filters.

Negative Combinations				
Frequency Filter	**GLPF**	**BLPF**	**GHPF**	**BHPF**
Cutoff Distances (Low-Pass Filter)	40	80	120	230
Cutoff Distances (High-Pass Filter)	40	80	120	NAN

Table 3. Combining power-law transform with frequency filters.

Power-Law Combinations				
Frequency Filter	**GLPF**	**BLPF**	**GHPF**	**BHPF**
Cutoff Distances (Low-Pass Filter)	40	80	120	230
Cutoff Distances (High-Pass Filter)	40	80	120	NAN
Power-Law Factor	5	3	5	NAN

The proposed method clarified the vascular impression in hilar regions in regular X-ray images, which can help radiologists in diagnosing vascular pathology, such as pulmonary embolism in case of thrombus that has been logged in pulmonary trunk, which will appear as a filling defect. The methodology also resulted in more detailed images hence, giving radiologists additional information about thoracic cage details including clavicles, ribs, and costochondral junction. Image enhancement assessment is subjective, unlike image restoration which also deals with improving the appearance of an image and is assessed objectively. Image restoration techniques tend to be based on mathematical or probabilistic models to test image degradations.

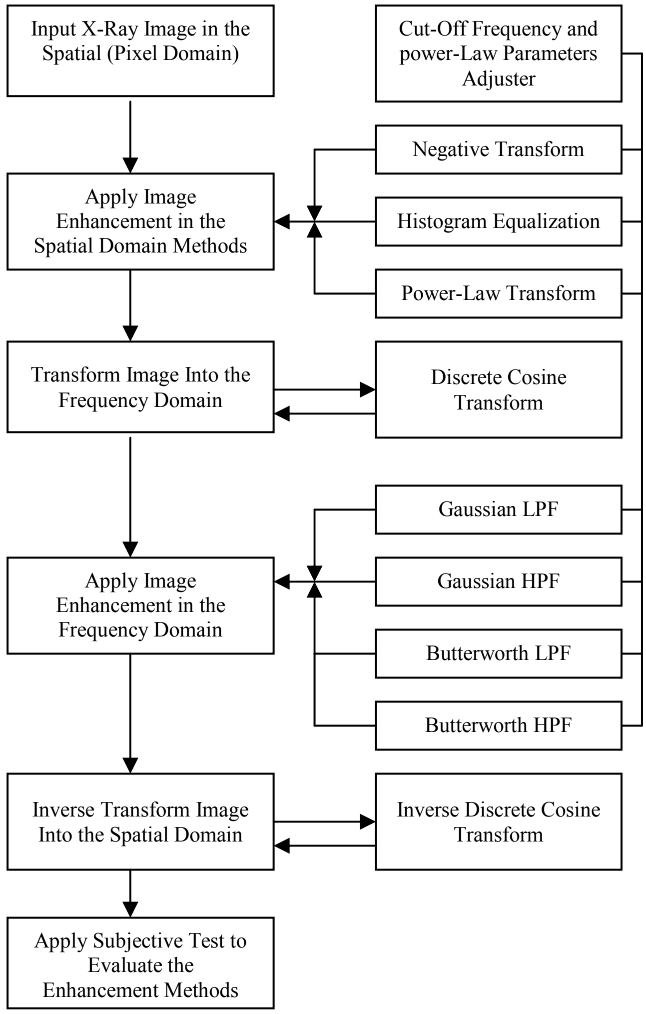


Figure 3. Block diagram of the proposed X-ray radiography image enhancement system.

5.1. Visual Quality Assessment

In order to evaluate and compare the performance of different image enhancement methods, it is necessary to judge the visual quality of the images being processed. As most imaging applications target human observers, the assessment on visual quality has to be relevant to the way the human visual system perceives an image. This brings challenges in the non-linear behaviour of the human visual system, and the variety of aspects that may influence measuring visual quality. This makes it a challenging mission and often leads to inaccurate results.

There has been limited research in the area of evaluating image enhancement/restoration techniques-by defining view-ability; even though interest in the topic is quite old [1, 6, 19]. Pappas *et al*., [18] state that: "Even though we use the term image quality, we are primarily interested in image fidelity, i.e., how close an image is to a given original or reference image". In their research they examine objective criteria for image quality that are based on HVS models, they also use three models that were proposed by [5, 14, 20] and gave comparative results. It should be noted that Daly and Lubin's models are exceptionally computationally complex and difficult to use for real-time applications.

Table 4. The X-ray image enhancement results obtained from combining different spatial and frequency domain methods, using different cu-off and power-law frequencies.

Experiments Results				
Possible Image Enhancement Combinations (Spatial+Frequency Domains)	**Enhancement Percentage (0-100%) Using Different Cut-Off Frequencies**			
	40	80	120	230
Negative+Gaussian LPF	20%	60%	70%	90%
Negative+Butterworth LPF	0%	10%	10%	10%
Negative+Gaussian HPF	10%	10%	10%	NAN
Negative + Butterworth HPF	30%	30%	40%	NAN
Histogram+Gaussian LPF	0%	0%	10%	5%
Histogram+Butterworth LPF	0%	5%	5%	2%
Histogram+Gaussian HPF	0%	0%	10%	NAN
Histogram+Butterworth HPF	50%	30%	30%	NAN
Power Law+Gaussian LPF Power Law Factor=0.5	0%	0%	10%	10%
Power Law+Butterworth LPF Power Law Factor=0.5	0%	0%	0%	0%
Power Law+Gaussian HPF Power Law Factor =0.5	5%	5%	5%	NAN
Power Law+Gaussian HPF Power Law Factor=0.5	20%	20%	20%	NAN
Power Law+Gaussian LPF Power Law Factor=0.3	0%	0%	0%	0%
Power Law+Butterworth LPF Power Law Factor=0.3	0%	0%	0%	0%
Power Law+Gaussian HPF Power Law Factor=0.3	0%	0%	0%	NAN
Power Law+Butterworth HPF Power Law Factor =0.5	0%	0%	0%	NAN
Power Law+Gaussian LPF Power Law Factor=0.5	0%	0%	0%	0%
Power Law+Butterworth LPF Power Law Factor=0.5	0%	0%	0%	0%
Power Law+Gaussian HPF Power Law Factor=0.5	0%	0%	0%	NAN
Power Law+Butterworth HPF Power Law Factor=0.5	0%	0%	0%	NAN

5.1.1. Subjective Quality Assessment

Human beings ability to assess the visual quality of an image is subjective and governed by many factors such as, the interaction level with the scene, spatial fidelity, and how comfortable the viewing environment is [21]. Designing quantitative view-ability measures that correlate well with the visual perception of different human experts still a challenging task. In order to set a standardised benchmark for subjective visual quality assessment, the International Telecommunications Union has proposed a set of test procedures defined in the International Telecommunications Union Recommendation [11]. This recommendation sets the guidelines for the subjective assessment test conditions such as the viewing distance, the test duration, and the observers' recruitment.

This research is targeted for radiologists, and therefore they are the image quality assessors. The original images (without processing) along with all the 80 possible enhancement methods were presented to a group consisting of four specialist radiologists in order to measure the enhancement percentage amount. Table 4 summarizes the results. Figure 4 shows a sample of the original images included in the test. It is clear that some combinations have yielded in excellent, above average, average, below average and no change enhancements. The use of GLPF at a cut-off frequency of 230 along with the negative transform has given the best results as shown in Figure 5, as it clarified the vascular impression clearly in both hilar regions, and helped in diagnosing vascular pathology. Other combinations such as the negative+butterworth high pass filter presented in Figure 6, and the histogram equalization+gaussian high pass filters presented in Figure 7 have shown some good results.

Figure 4. Chest x-ray image for testing the proposed method (original image) courtesy of “medpix” the medical image database, radiology teaching files [15].

Figure 5. A 90% enhancement obtained by combing Negative transform with GLPF and applying them on Figure 3, original image is courtesy of “medpix” the medical image database, radiology teaching files [15].

Figure 6. Enhancement obtained by combing Negative transform and Butterworth High Pass filter and applying them on Figure 3, original image is courtesy of “medpix” the medical image database [15].

Figure 7. A 70% enhancement obtained by combing negative transform with GLPF and applying them on Figure 3, original image is courtesy of “medpix” the medical image database, radiology teaching files [15].

6. Conclusions

Degradation of digital X-ray medical image such as low contrast and blurring during radiographic imaging, caused by the complexity of the body tissue and by the effects of X-ray scattering and electrical noise, can negatively influence the subsequent analysis and diagnosis carried out by the radiologists. Image enhancement is used to process an image so that the result is more suitable than the original image for a particular application. This paper presented and novel hybrid methods for enhancing digital X-ray images. Selected methods from the spatial and frequency domains have been combined to give over 80 possible combinations to be tested, where some of the combinations have resulted in the best possible enhancement compared to the original image, according to radiologist subjective assessments. The results have clearly shown that combining the negative transform with the GLPF under radii of 230 has resulted in the best enhancement gained. The proposed methods have clarified the vascular impression in hilar regions in regular radiographs.

The proposed work is intended to assist radiologists in diagnosing vascular pathology, such as Pulmonary Embolism. From a medical point of view, the results gave radiologists added information about thoracic cage details including clavicles, ribs, and costochondral junction.

Acknowledgements

The authors would like to express their sincere thanks to the radiology departments including both the radiologists and the staff-members working at Prince Hamza, and Al-Bashir hospitals, for facilitating the assessment part of this research. Special thanks go for Dr. Issam Sa'adeh for his special efforts and generous help.

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