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ENHANCEMENT TECHNIQUES FOR MRI HUMAN SPINE IMAGES

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Graphical abstract

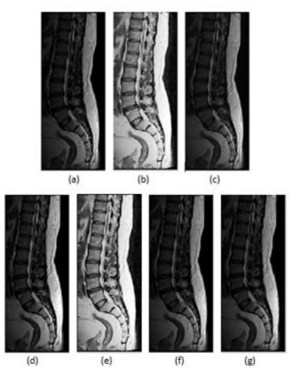


Fig. 6 Enhancement of (a) original image MRI human spine images using (b) proposed method (c) wavelet transform (d) contrast stretching (e) histogram equalization (f) Gaussian filter and (g) median filter.

Abstract

The quality of Magnetic Resonance Image (MRI) determines the accuracy of clinical diagnosis. It provides information about the human soft tissue anatomy. MRI of spine is used by the physicians to evaluate any presence of diseases including slipped disk, herniated disk, trauma and disk degeneration. Existence of noises and artifacts can degrade the quality of the MR images. Thus, appropriate image processing techniques may help to improve the quality of the acquired image. Preprocessing is usually done to remove the noise, enhance an image boundary and adjust the image contrast. Current techniques to enhance and reduce noise in MRI human spine are discussed and a method using discrete wavelet transform to enhance the MRI of human spine is proposed. The resultant images are evaluated quantitatively. This study shows that the proposed method has better results as compared to other existing method based on evaluation tests.

Keywords: MRI, medical image processing; image enhancement; spine; statistical evaluation

Abstrak

Kualiti imej Magnetic Resonance Image (MRI) menentukan ketepatan diagnosis kerana ia memberi infomasi tentang tisu lembut badan manusia. Pakar perubatan menggunakan imej MRI tulang belakang manusia untuk menilai sebarang penyakit spina seperti cakera tergelincir, cakera melejit, trauma dan degenerasi cakera. Kehadiran artifak dan hingar dalam imej menjejaskan kualiti imej MRI. Oleh itu, teknik pemprosesan imej yang sesuai boleh meningkatkan kualiti imej. Tujuan pra pemprosesan imej adalah untuk mengurangkan hingar, menambah sempadan imej dan melaraskan kontras imej. Teknik penambahbaikan imej yang tersedia telah dikaji dan satu teknik telah dicadangkan dengan menggunakan jelmaan wavelet dan penyamaan histogram. Imej MRI yang telah diproses akan dinilai secara kuantitatif. Penyelidikan ini berjaya menunjukkan teknik cadangan memberi keputusan yang lebih baik berbanding dengan teknik-teknik yang lain.

Kata kunci: MRI, pemprosesan imej perubatan; peningkatan imej; tulang belakang; penilaian statistik

1.0 INTRODUCTION

A patient is required to receive magnetic resonance imaging (MRI) scan for spine diseases and injuries. MRI is an advanced medical imaging technique because it has unique ability to provide details about structural features of internal body tissue including spinal disk, nerve, spinal cord and spinal fluid. It allows the assessment of any abnormalities of the spine. This harmless technology applies strong magnetic field and radio waves to produce image. The advantage of using MRI is that it does not produce radiation and hence, prevents X-ray radiation exposure to the subject. However, the visual quality of the image is often degraded due to the existence of noises and artifacts during acquisition process. Artifacts are caused by physiological motions such as, bowel movement, cardiovascular pulsation, respiratory motion and physical movement of subjects [1]. These noises and artifacts cause the reduction of anatomic detail, clarity of image and blur the edge, thus having difficulty to detect any abnormalities from the MRI image.

Image processing is one of the solution to improve the interpretability of information in image for better visual by applying algorithms to process the image. Preprocessing an image includes removal of noise, enhancement of edge or boundary, automatic edge detection, contrast adjustment and segmentation [2]. The preprocessing step is not only increase the accuracy of the diagnosis but also reduce the time and labor cost [3]. However, different image enhancement methods may only suitable for a specific image modality and application. Image enhancement remains the information content of data and increases the dynamic range of the region of interest. Generally, enhancement is to enhance the low contrast part of image, thus create a better visual quality of image. Image enhancement methods can be operated based on either spatial or frequency domain.

The main objective of this paper is to study and compare the existing techniques for image enhancement, including histogram equalization (HE), contrast stretching and various type of filters. Most of these techniques are on spatial domain. An enhancement to an image can also be made in frequency domain. A discrete wavelet transform is proposed to enhance the MRI human spine image. The resultant images of each enhancement method are evaluated quantitatively.

This paper is organized as follows. Section 2 discusses several existing enhancement techniques. Basic equations and graphs are explained. Section 3 introduces multiresolution analysis and wavelet transform. Section 4 discusses the results and findings of this work. Section 5 presents the conclusion.

2.0 EXISTING ENHANCEMENT METHODS

There are various types of enhancement techniques used to increase the contrast of the MRI images. Some of the basic enhancement methods are discussed in this section.

2.1 Histogram Equalization

Histogram is a statistical feature of an image. The distribution of all pixels within an image is presented with an intensity histogram. The distribution of pixels is not uniform within a data range. This causes some details of the image become unclear. The techniques remap the gray levels of images based on probability distribution of the input grey levels [4]. It adjusts image intensities to enhance contrast by extending the accumulate intensity part. The histogram of transformed image is even and uniform, thus the details of the image is enhance.

$$P_n = \frac{number\ of\ pixels\ with\ intensity n_k}{total\ number\ of\ pixels\ n}, n = 0,1, \ldots, L-1 \quad (1)$$

Let *P* represents the normalized histogram of image *f* with a bin for each possible intensity. *n* is the range of integer pixel intensities and *L* is the number of possible intensity value.
Transforming the pixel intensities, *k,* of *f* by function

$$T(k) = floor[(L-1)\sum_{n=0}^{k} P_n] \quad (2)$$

where floor() rounds down value to the nearest integer.

Despite simple and easy to implement, histogram equalization has drawback. Histogram equalization allocates one gray level into neighboring gray levels with different value of intensities. If histogram equalization allocates a gray level with higher intensity to the specific gray level, it gives washed out appearance to the processed image [5]. Histogram equalization can initiate a considerable change in brightness of an image obtain a maximum value of the uniformly distributed image [5].

2.2 Contrast Stretching

Contrast of an image is the measure of dynamic range which defined as the range of intensity values contained within an image. For an 8-bit image, it has a dynamic range of 256. Hence, it can take values from 0 to 255, where 0 represents black, 255 represents white and the intermediate pixels values represent grey. Values that are less than the dynamic range will result a lower contrast image. Several of factors that contributed to a low contrast image include lack of illumination, deficiency of dynamic range in the image sensor and wrong setting of a lens aperture during image acquisition phase [6]. Contrast stretching is a method to stretch all the intensities so that it extends full dynamic range.

Contrast stretching is limited to linear scaling function of input to output values. For each pixel *k*,

$$b[m,n] = \frac{a[m,n]-min}{max-min}(2^n - 1) \quad (3)$$

where *min* is the minimum pixel value, *max* is the maximum pixel value and *n* is the number of bit of an image.

However, the disadvantage of using this method is that outlying pixel which is either very high or very low value can affect the effectiveness of this operation. This could yield to an unrepresentative scaling. Therefore a restricted range of input values need to be determined by plotting a histogram of an image and select the new maximum and minimum pixels which are at 5th and 95th percentile in the histogram instead of 0th and 100th percentile.

$$b[m,n] = \begin{cases} 0, & a[m,n] \le min_{0.05} \\ \frac{a[m,n]-min_{0.05}}{max_{0.95}-min_{0.05}}(2^n - 1), & min_{0.05} < a[m,n] < max_{0.95} \\ (2^n - 1), & a[m,n] \ge max_{0.95} \end{cases} \quad (4)$$

Where $min_{0.05}$ and $max_{0.95}$ are 5th and 95th percentile pixels value in the histogram. Besides, another drawback for this method is that graininess property appears in the modified image.

2.3 Gaussian Filtering

Gaussian is useful for image smoothing. It used as low pass filter. Gaussian function in frequency domain is represented as

$$g(x,y) = A\, exp\frac{-(x^2-y^2)}{2\sigma^2} \quad (5)$$

where *A* is a scale factor and is set to a value so that area under the curve of normal distribution is 1. σ denotes the standard deviation of the curve. The standard deviation value, σ determined the degree of smoothing effect [7]. The main advantage of using Gaussian filter is that it smoothen the image but also preserve the edge since edge contain many high frequencies.

2.4 Median Filter

Median filter is an order-statistics, non-linear based filtering algorithm. Any image pixel is substituted by the median of the image pixels in the neighborhood of that pixel. The median value is calculated by first listing out all the values of pixel in the square kernel into numerical order and replaced the considered value which is located at the center of the kernel with the median of all the pixel values in the kernel. If it has even number of neighborhood consideration, the median value can be obtained by averaging the two middle values.

It has ability to remove impulse noise which is the outlying pixel. The median value will not be affected by the outlying pixel significantly. Besides, the median value is one of the pixels in the neighborhood. The filter does not create a new pixel value to replace the considered pixel, thus it preserves the edges without blurring. This type of filter belongs to the type of edge preserving smoothing filter [8].

3.0 WAVELET TRANSFORM

One of the important characteristic of wavelet transform is the multi-resolution analysis (MRA). The main purpose of this analysis is to obtain different approximations of function *f(x)* at different levels of resolution [9]. MRA analysis is found to be successful for image denoising and enhancement problems. It separates signal and noise by transform domain based on their distinct localization and distribution in the spatial-frequency domain [10]. The basic function of wavelets are mother wavelet, $\psi(x)$ and scaling function $\varphi(x)$.

3.1 Scaling Function, φ(x)

The purpose of scaling function, $\varphi(x)$ is to approximate an image function at different level of approximations. Each approximation is down-sampled by a factor of two, to from approximated image in next subsequent resolution [9]. It is an expansion functions and can be represented by the following equation

$$\varphi_{j,k}(x) = 2^{j/2}\,\varphi(2^j x - k) \quad (6)$$

This function has two integer parameters which are *j* and *k* which determine the position of $\varphi_{j,k}(x)$.

3.2 Wavelet Function, ψ(x)

Wavelet function is a type of scaling function that fulfilled the four MRA conditions which are

- The scaling function has to be orthogonal to its integer translates.
- The function space V_j spanned by a set of function $\varphi_{j,k}$ is a subspace of function space V_{j+1} spanned by function $\varphi_{j+1,k}$.
  $$V_{-\infty} \subset \cdots \subset V_{-1} \subset V_0 \subset V_1 \subset \cdots \subset V_\infty \quad (7)$$
- The only function that contained all subspaces V_j is $f(t)=0$.
- A function can be represented with arbitrary precision. Any square-integrable function can be represented by
  $$V_\infty = L^2(R). \quad (8)$$

The function of wavelet can be represented as

$$\psi_{j,k}(x) = 2^{j/2}\,\psi(2^j x - k). \quad (9)$$

3.3 Discrete Wavelet Transform (DWT) in Two-Dimension

Wavelet transform decomposes the input signal into set of directional wavelet functions and scaling function which are:

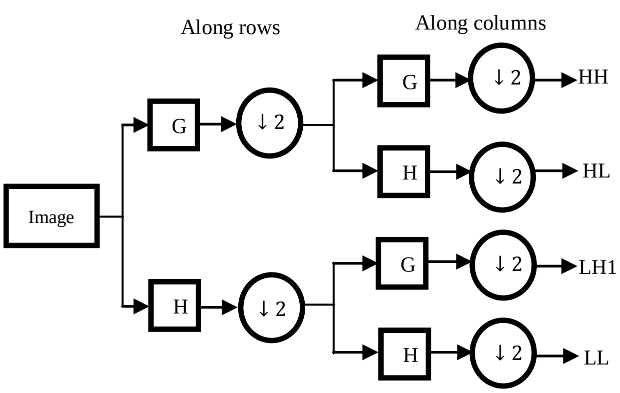
$$\varphi(x,y) = \varphi(x)\varphi(y), \quad (10)$$

$$\psi^H(x,y) = \psi(x)\varphi(y), \quad (11)$$

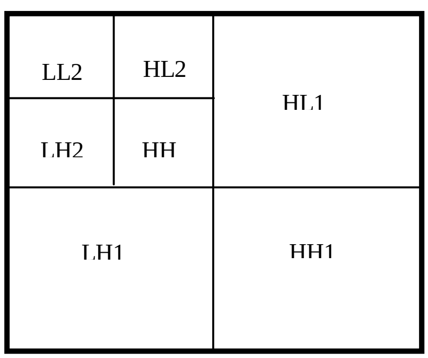
$$\psi^V(x,y) = \psi(y)\varphi(x), \quad (12)$$

$$\psi^D(x,y) = \psi(x)\psi(y), \quad (13)$$

where ψ^H, ψ^V, and ψ^D detects the horizontal variation, vertical variation and diagonal variation respectively. DWT divides signal into approximation and detail by signal decomposition as illustrated in Figure 1 (a) by using high pass filter (G), low pass filter (H) and also down sampled by 2 as represented by the circle. Figure 1 (b) shows the resultant sub-band produced by the two levels discrete wavelet transform.



(a)



(b)

Figure 1 (a) shows one level 2-D discrete wavelet transform decomposition and (b) shows two levels discrete wavelet transform sub-band.

4.0 MEASUREMENT OF EACH ENHANCEMENT METHODS

After the MRI spine images are processed using each method, all the images are evaluated quantitatively. Quantitative measurements are performed to get the statistical value of original image, $(g_{i,j})$ and enhanced image, $(f_{i,j})$. The measurements are contrast enhancement (C), signal to noise ratio (SNR) and contrast to noise ratio (CNR).

5.0 RESULTS AND DISCUSSION

In this paper, MRI spine images are used to undergo the preprocessing process based on different type of techniques and also our proposed technique. The tested images are contributed by our collaborators in the Department of Radiology, HUKM. There are a total of 3172 of MRI human spine images. We choose 50 MRI human lumbar spine images by limiting our images to have only sagittal view since it is the most efficient view to detect the presence of any slipped disks – one of our interest to explore for future work. All images were normalized to have a zero mean and a unit standard deviation. This is to provide a consistency in dynamic range among the images. These images are manually cropped into size of 320x130.

The proposed preprocessing technique is divided into two parts which are the processing in frequency domain using discrete wavelet transform, followed by enhancing the image in spatial domain by using histogram equalization. Discrete wavelet transform has the ability to separate the details in the image, and thus we are able to selectively enhance the high frequency content of the images as shown in Figure 2. This is important to preserve the edges. Then, the histogram equalization is performed on the enhanced image to globally increase the overall contrast. With this combination, we will have an enhanced image with preserved edges. Figure 3(a) shows one of the randomly selected MRI image and the corresponding enhanced image using different enhancement methods.

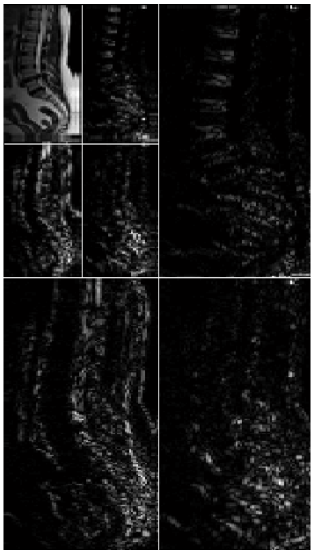


Figure 2 Two levels wavelet decomposition of MRI spine image.

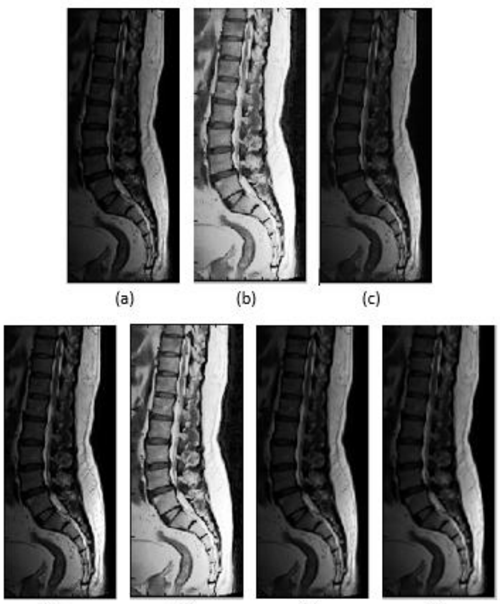


Figure 3 Enhancement of (a) original image MRI human spine images using (b) proposed method (c) wavelet transform (d) contrast stretching (e) histogram equalization (f) Gaussian filter and (g) median filter.

For the detection of slipped disk, the edge or boundary of the vertebra needs to be clear and sharp. As illustrated in Figure 3, the proposed method and histogram equalization method visually give better enhancement images as compared to the other methods. Moreover, from observation, most of the images (44 from 50 tested) have shown good contrast improvement when the proposed method was applied. The image has granular appearance by using the contrast stretching. Others techniques do not show much improvement.

However, when the images are quantitatively compared, our proposed method proved to be improved. The results are presented in Table 1. From the statistical data obtained, the proposed method has the highest mean value in both *CNR* and *C* with lowest *SNR* value.

Table 1 Experimental results

	SNR	CNR	C
Proposed method	**$0.39e10^{-6}$**	**8.07**	**80.25**
Contrast stretching	$7.62e10^{-6}$	3.62	42.81
Histogram Equalization	$0.41e10^{-6}$	7.90	79.26
Gaussian filter	$239.32e\ 10^{-6}$	2.95	33.22
Median filter	$84.48e\ 10^{-6}$	2.86	36.16

6.0 CONCLUSION

This paper proposes a new contrast enhancement method that combines the enhancement in spatial and frequency domains for MRI spine images. The results show that the proposed method has improved the MRI images' contrast as compared to other basic enhancement methods. MRA analysis enable us to analysis data at multiple resolutions hence, allows the enhancement of image details at different resolutions. With these properties, wavelet transform able to preserve the information in the image, which is important to secure significant information in medical images. Our proposed method has bright potential to be explored for computer aided design (CAD) system and medical image retrieval system (MIRS).

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