COMPARATIVE STUDY OF TWO PROPOSED METHODS FOR IMAGE ENHANCEMENT OF ABNORMAL MRI BRAIN IMAGES IN SPATIAL AND FREQUENCY DOMAIN

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Abstract:

Image enhancement is the part of image pre-processing that is used to improve image quality and adjust image information content for further processing and includes techniques such as removing noise or reducing noise levels to a certain extent, adjusting contrast, sharpening the image, etc. In this research, 5 original grayscale images which are abnormal magnetic resonance imaging (MRI) brain images have been processed by using enhancement techniques in two different domains, spatial and frequency. This research described method of enhancement abnormal MRI brain images by using combining spatial domain techniques in MATLAB and method of enhancement abnormal MRI brain images by using combined 2-D stationary wavelet transform for denoising in Wavelet Analyzer technique within MATLAB and filtering in frequency domain technique in MATLAB. Image data used in this research were obtained from Radiopaedia, an educational radiology resource. The best technique to applied on abnormal MRI brain images has been detected by comparing the results of peak signal to noise ratio (PSNR), signal to noise ratio (SNR) and mean square error (MSE). Based on results obtained for PSNR, SNR and MSE measurements, it has been concluded and confirmed that better results for image enhancement of abnormal MRI brain images gives us combining spatial enhancement techniques.

Keywords:

magnetic resonance imaging (MRI), stationary wavelet transforms, spatial domain, frequency domain, Wavelet Analyzer.

INTRODUCTION

Image processing is a method that processes a digital image using an algorithm in MATLAB and thus performs certain operations on image elements to obtain corresponding modified results that are better than the original image or to extract the necessary information from the image. In this paper, techniques for enhancement MRI brain tumours images will be presented. Magnetic Resonance Imaging (MRI) is one of the diagnostic methods in radiology that is used to detect patients' diseases, for example, to detect and analyze some changes in brain soft tissue. Image enhancement is method used for improving image quality, removing or reducing noise, deblurring and sharpening details in an image, adjusting contrast of an image in order so that enhanced images can be utilized by human observer, in case of MRI images, by medical specialists.

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Imaging enhancement techniques play a significant role in MRI image pre-processing, especially in applications for diagnosing and detecting abnormal brain tissue based on human vision. Significant improvements in image quality can help medical specialists to interpret MRI images. In this paper, abnormal original MRI brain image which having low contrast and a certain amount of noise is applied to get some useful information about, for example, size, shape, location of abnormal tissue in the brain. This paper gives comparative study of two proposed techniques of image enhancement of brain tumour MRI images. First technique is combining Stationary Wavelet analysis using Wavelet Analyzer for denoising and combined spatial enhancement methods using MATLAB. Second technique is combining Stationary wavelet analysis using Wavelet Analyzer for denoising and filtering in frequency domain, also using MATLAB. Images data used in this paper are obtained from Radiopaedia, an educational radiology resource.

2. INTERACTIVE 2-D STATIONARY WAVELET TRANSFORM

Wavelet analysis can denoise image without significant degradation of an image just because it provides a different view of a data [1]. In this paper, it is applied 2-D stationary wavelet transform for denoising image using Wavelet Analyzer application.

2.1. OVERVIEW OF A STATIONARY WAVELET TRANSFORM FOR DENOISING IMAGE

In image processing applications, wavelet transform is a technique used to limit the time scale of a window to match the original image and is especially important and useful for non-stationary analysis of signals such as noise. For the purpose of image de-noising, it is suitable to use stationary wavelet transform (SWT) because it makes wavelet decomposition time invariant, it has equal of wavelet coefficients at each level, decomposition is redundant obtained by supressing the down sampling operations and up-sampling procedure is applied before we separate the variables *x* and *y* like shown in the following wavelets (vertical, horizontal, diagonal) [2-3]:

$$\begin{aligned} \varphi^{1}(x,y) &= \phi(x)\varphi(y) \\ \varphi^{2}(x,y) &= \phi(x)\varphi(y) \\ \varphi^{3}(x,y) &= \phi(x)\varphi(y) \end{aligned} \tag{1}$$

where φ is a wavelet function and ϕ is a scaling function.

2.2. PROPOSED METHOD

In this paper, it is applied 2-D stationary wavelet transform for denoising image using Wavelet Analyzer application. Image de-noising is used to remove or reduce the additive noise on certain level while retaining as much as possible the important features. The wavelet denoising is achieved via thresholding. Wavelet thresholding procedure removes noise by thresholding only the wavelet coefficient of the details coefficients, by keeping the low resolution coefficients unaltered. There are two thresholding methods frequently used: soft thresholding and hard thresholding. The hard thresholding is chosen over soft thresholding because hard thresholding gives us better PSNR, SNR and MSE results for our research [4].For decomposing original abnormal MRI brain image 800x800 at level 1 to 4, we applied *haar* wavelet through SWT because it gives best results for image quality evaluation [2]. The procedure for denoising image through SWT using Wavelet Analyzer in MATLAB follows next steps:

1. Load original abnormal MRI brain image 800x800 pixels in MATLAB m-file.
2. In the SWT Denoising 2-D tool import image from workspace.
3. Perform SWT decomposition using *haar* wavelet from Wavelet menu, select 4 from Level menu and then use Decomposition button.
4. Apply hard Penalize Low threshold method over detail coefficient obtained by *haar* wavelet (Vertical, Horizontal, Diagonal).
5. After thresholding, new details of the coefficients were obtained on the basis of which we reconstructed the image and obtained a denoised image.
6. Save denoised image and filename in specify folder.

3. SPATIAL DOMAIN METHODS

In the spatial domain, spatial domain techniques are based on direct operations on the pixels of the original image. The advantage of using spatial domain techniques to improve the image is that they are easier to implement and apply to images through an algorithm by improving the image in a uniform way. However, in some cases this can be a flaw depending on the type of image being processed. Two approaches are used to improve images in the spatial domain: point processing operations and spatial filtering operations.

Point processing operations are performed on a single image element where the value of that element depends on the value of the original image element. The following techniques can be used in this approach: negative transformation, log transformation, thresholding transformation, power law transformation [5]. To transform the intensity of the image, spatial filtering operations are used, which are applied to the corresponding pixel and its neighbouring pixels. There are two approaches that can be applied: linear filtering and nonlinear filtering. Linear filtering replaces the value of each pixel in the original image by the average of the gray levels on the corresponding pixel and its neighbouring pixels defined by the filter mask. We need to combine several spatial domain techniques in order to achieve an acceptable result in image enhancement.

3.1. THE SECOND DERIVATIVE FOR IMAGE SHARPENING – LAPLACIAN

In this paper, we use 2D second-order derivative – Laplacian for the sharpening of an image, which we first define with a discrete formulation, and then we construct a filter mask based on that formulation. For a function (image) of two variables *f (k,j)* is defined as:

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} \quad . \tag{2}$$

To express this equation in discrete form, we use the definition

$$\frac{\partial^2 f}{\partial x^2} = f(x+1) + f(x-1) - 2f(x) \, . \tag{3}$$

In x-direction we have

$$\frac{\partial^2 f}{\partial x^2} = f(x+1,y) + f(x-1,y) - 2f(x,y) \, . \tag{4}$$

In y-direction we have

$$\frac{\partial^2 f}{\partial y^2} = f(x,y+1) + f(x,y-1) - 2f(x,y) \, . \tag{5}$$

The discrete Laplacian of two variables is

$$\begin{aligned} \nabla^2 f(x,y) = {} & f(x+1,y) + f(x-1,y) \\ & + f(x,y+1) + f(x,y-1) \\ & - 4f(x,y) \, . \end{aligned} \tag{6}$$

The basic way in which we use the Laplacian for image sharpening is:

$$g(x,y) = f(x,y) + [\nabla^2 f(x,y)] \tag{7}$$

where *f(x,y)* and *g(x,y)* are the input and sharpened images respectively.

3.2. AVERAGE FILTER

Average filtering is a method of smoothing the image so that the filter replaces each pixel value of the image with the average pixel value (pixel by pixel) using gray level values and thus reduces the amount of intensity variation between neighbouring pixels. Smoothing the image reduces or eliminates noise.

3.3. SOBEL OPERATOR FOR (NONLINEAR) IMAGE SHARPENING – THE GRADIENT

The Sobel operator is a discrete differentiation operator that calculates the gradient approximation of the image intensity function. In this paper, the Sobel operator is based on the convolution of the original image and two 3x3 filter masks with integer values in the horizontal and vertical directions to calculate the approximation of the derivative - the first filter mask *Gx* for horizontal changes and the second filter mask *Gy* for vertical changes.

$$Gx = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} * A, \quad Gy = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} * A \tag{8}$$

The magnitude (length) of the Sobel operator gradient vector *B(x,y)* can be calculated:

$$B(x,y) = \sqrt{G^2 x + G^2 y} \, , \tag{9}$$

where is the value at *(x,y)* of the rate of change in the direction of the gradient vector.

3.4. POWER LOW TRANSFORMATION

Power-law transformations can be calculated as:

$$s = cr^{\gamma} \tag{10}$$

where c and γ are positive constants.

The exponent in the power-law equation is referred to as gamma. Whether the image will be corrected properly, meaning changing intensity of pixels properly, depends on the gamma parameter. If the properly correction is not applied, the image may be too faded or too dark.

3.5. PROPOSED METHOD

In order to get an acceptable result in image enhancement, we will apply a combination of several spatial domain techniques on abnormal MRI brain image 800x800 pixels [6-10]. The aim of this proposed method is to enhance the image by focusing and highlighting more details of the soft tissue of the brain. We will use Laplace to highlight fine details and Sobel gradient to further emphasize the edges. We can obtain a sharpened image by simply adding the original image and the Laplacian of the original image according to equation (7). As a result, we obtained a noisy sharpened image. In order to reduce noise from sharped image, an alternative approach is to use a mask formed from smoothed version gradient of original image. Sobel gradient is obtained applying equation (9). Components *Gx* and *Gy* are obtained using equation (8). Sobel gradient is chosen over Laplacian gradient because of the gradient of an image with significant edge content has values that are higher in general than in a Laplacian image. A smoothed version gradient of original image is obtained by using average filter 3x3 and Sobel gradient. Next step is obtaining image as the product of Laplacian and smoothed-gradient image for resulting strong edges and reducing visible noise on the image. Adding product image to the original image resulted in sharpening image and obtained image in which can be noticed significant increase in sharpness of detail over the original image [11]. Final step is applying power low transformation over last resulted sharped image by equation (10) where γ=0.3 in order to increase dynamic range intensity of the pixels in image. In the end, PSNR, SNR and MSE is calculated directly in MATLAB using in-build function *psnr* and *immse* and results are obtained showed in Results and Discussion. In-build function psnr automatically calculates SNR measure too. In this paper, we used the built-in functions from the Image Processing Toolbox in MATLAB.

4. FREQUENCY DOMAIN METHODS

In frequency domain, frequency domain techniques are based on operations on the Fourier transform of the original image instead of pixels of the image itself. Image enhancement in frequency domain is a method by which certain operations are performed on transformation coefficients of an image such as Fourier transform, discrete wavelet transform, discrete cosine and sine transform.

4.1. GAUSSIAN HIGH-FREQUENCY EMPHASIS FILTERING FOR IMAGE SHARPENING

Sharpening of the image in the frequency domain is achieved by high-pass filtering because the nature of the edges in image and other sudden changes in the intensity of the image is such that it is closely related to high-frequency components. The transfer function of the Gaussian high pass filter (GHPF) with cut-off frequency is given by:

$$H(u,v) = 1 - e^{-D^2(u,v)/2D_0^2} \tag{11}$$

where D_0 is constant and $D(u,v)$ is given by

$$D(u,v) = \left[(u - \frac{P}{2})^2 + (v + \frac{P}{2})^2 \right]^{1/2}. \tag{12}$$

General formulation of high-frequency-emphasis filtering is given by:

$$g(x,y) = I^{-1}\left\{ \left[k_1 + k_2 * H_{HP}(u,v) \right] F(u,v) \right\} \tag{13}$$

4.2. HISTOGRAM EQUALIZATION

Histogram equalization is the most commonly used technique for contrast adjusting of an image. The aim is to produce a more uniformly distributed histogram of the image in order to evenly stretch out the gray levels of pixels and obtain a much clearer image.

4.3. PROPOSED METHOD

In this paper, it is used abnormal original MRI brain image 800x800 [6-10] denoised by 2-D SWT using wavelet analyser, following steps in proposed method 2.2, as an input image. A denoised image is first converted into grayscale from RGB. Then using Gaussian high pass filter in combination with high-frequency emphasis

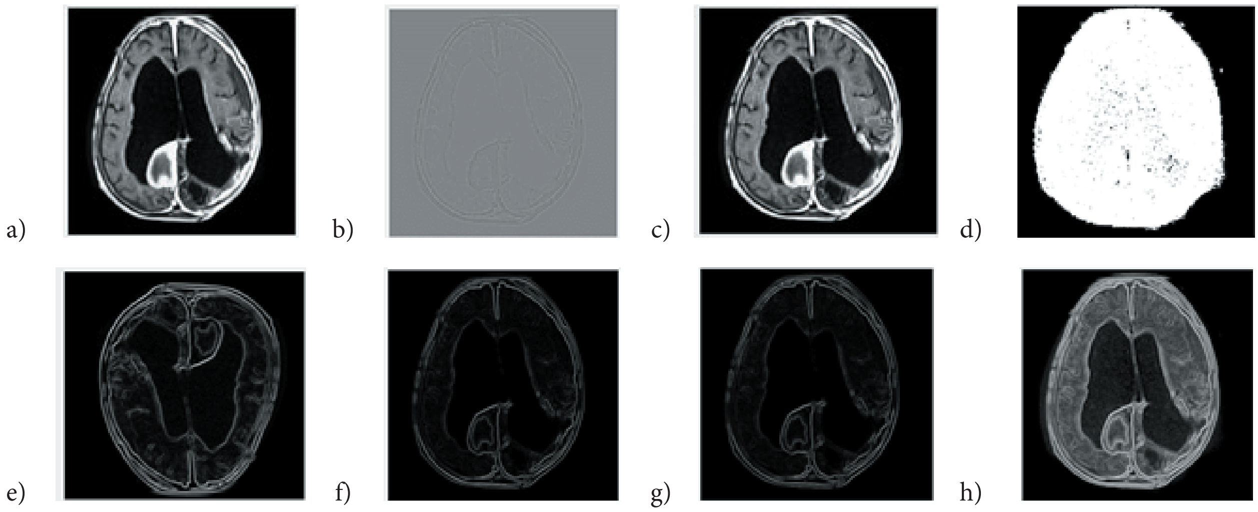

Figure 4 - a) Abnormal original MRI brain image; b) Laplacian with scaling of a); c) Sharped image obtained by adding a) and b); d) Sobel gradient of a); e) Sobel image smoothed by averaging 3x3 filter; f) Mask image formed by the product of c) and e); g) Sharped image obtained by the sum of a) and f);
h) Final result obtained by applying a power-low transformation to g).

filtering implemented by equation (11) and (13) where D_0=3.5, k_1=0.5 and k_2=1.5 high-frequency emphasis filtered image is synthesizes and visualized. MATLAB in-build *fft* function is used for spectral extraction. Final step is histogram equalization applying on an filtered image using MATLAB in-build function histeq. In the end, PSNR, SNR and MSE is calculated directly in MATLAB using in-build function *psnr* and *immse* and results are obtained showed in Results and Discussion. In-build function *psnr* automatically calculates SNR measure too [12].

5. RESULTS AND DISCUSSION

This paper elaborates different methodologies for enhancement a brain tumour MRI providing an insight as to which algorithm should be utilized for more reliable estimate of the original image using PSNR, SNR and MSE evaluation factors [4]. Image data used for this paper are obtained from Radiopaedia, an educational radiology resource. The abnormal original MRI brain images 800x800 pixels [6-10] has been enhanced by various methods.

In proposed method for image enhancement in spatial domain, image has been enhanced by focusing and highlighting more details of the soft tissue of the brain for better features visualization of tumour and the rest of soft tissues of the brain. Combining spatial filtering and intensity transformations of pixels techniques for image enhancement gives us visualized results showed in Figure 4. The effective enhanced images are obtained by using algorithm following proposed spatial enhancement. According to the human vision, the quality of the enhanced images is found to be better than that of the original image because the internal structure of the image becomes clearer meaning image is denoised, deblurred, edges of soft tissues are clearer. For human vision, a disadvantage for MRI brain image enhancement processing using this combination techniques in spatial domain are that dynamic range of pixels intensity is uniform.

There are 5 MRI brain tumour images over which is applied algorithm for combined spatial enhancement method. The higher PSNR indicates the high quality of the MRI brain image results. MSE measure strongly depends on the image intensity scaling. The measurements of the abnormal MRI brain grayscale images using the spatial techniques are described in Table 1. All of the MRI images are processed through the MATLAB code.

MRI images	PSNR	SNR	MSE
I_1[6]	15.7935	6.0805	1712.8970
I_2[7]	15.2719	4.5354	1931.4874
I_3[8]	19.4009	8.6787	746.4243
I_4[9]	14.7724	7.0896	2166.9105
I_5[10]	14.9279	5.6762	2090.6931

Table 1 - Resulted PSNR, SNR, MSE measurements

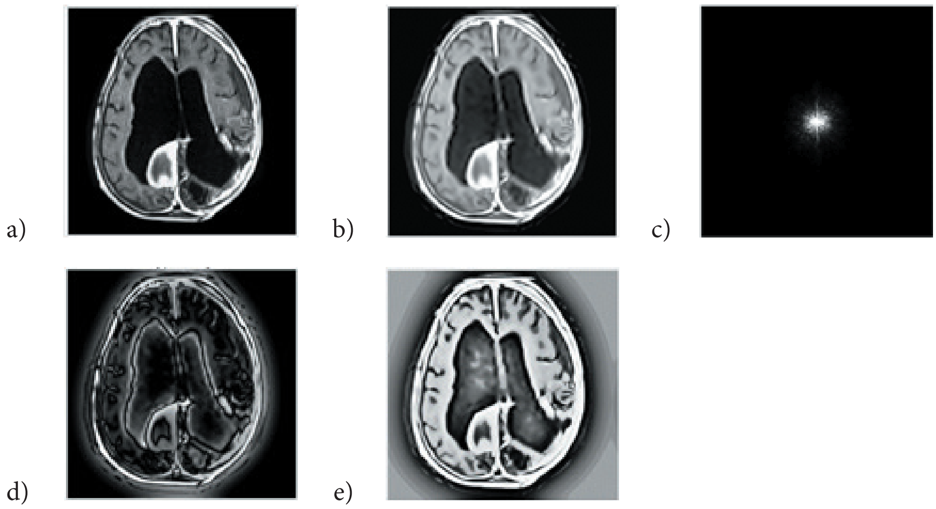

Figure 5 - a) Abnormal original MRI brain image; b) Denoised image through SWT; c) Fourier transform of an image; d) Image obtained by Gaussian high pass filter in combination with high-frequency emphasis filtering applied on image b); e) Resulted image of histogram equalization applied on image d).

In proposed method for image enhancement in frequency domain by combining technique for denoising through SWT using wavelet analyser and filtering technique for sharpening image alongside histogram equalization for contrast adjustment gives also effective results visualized in Figure 5. Denoising image through SWT also has effect of smoothing an image.

The measurements of the abnormal MRI brain grayscale images using the frequency domain techniques are described in Table 2. All of the MRI images are processed through the MATLAB code.

MRI images	PSNR	SNR	MSE
I_1[6]	11.0792	5.7635	5071.8185
I_2[7]	6.8051	1.1259	13569.7795
I_3[8]	6.0815	1.9607	16030.0327
I_4[9]	5.3789	1.9302	18844.6966
I_5[10]	6.0064	2.0366	16309.5519

Table 2 - Resulted PSNR, SNR, MSE measurements

Based on Table 1 and Table 2, we can conclude that the better results for PSNR, SNR and MSE measurements are obtained by applying algorithm for combining spatial enhancement method on abnormal original MRI brain images than applying algorithm for combining SWT and frequency enhancement method.

6. CONCLUSION

The effective enhanced images are obtained by using algorithm following proposed spatial enhancement. According to the human vision, the quality of the enhanced images is found to be better than that of the original image because the internal structure of the image becomes clearer meaning image is denoised, deblurred, edges of soft tissues are clearer. For human vision, a disadvantage for MRI brain image enhancement processing using this combination techniques in spatial domain are that dynamic range of pixels intensity is uniform. The effective enhanced images are also obtained by using algorithm following proposed method for frequency enhancement techniques in MATLAB and Wavelet Analyzer application within MATLAB. Dynamic range of pixels intensity is extended applying histogram equalization. Based on results obtained for PSNR, SNR, MSE measurements, we can conclude that better results for image enhancement of abnormal MRI brain images provides us combining spatial enhancement techniques.

There is room for further research in the direction of combining some other techniques for image sharpening, image smoothing etc. to enhance MRI images in the frequency domain in order to get better results.

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