Efficient Enhancement of ultrasound images of abnormal kidney

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Abstract: Recently, ultrasound imaging has become one of the most preferred imaging techniques amongst other than medical imaging techniques as it is reasonably priced, extensively accessible and relatively safe to user due to its safety radiation method. Nevertheless, the existence of speckle noise and low resolution in all ultrasound images affect the quality of the images which cause the difficulties in the interpretation of ultrasound images. Accordingly, ultrasound image enhancement technique is an essential process for superior disease diagnosis as well as for detection of pathological kidney damage precisely. In this study, five contrast enhancement techniques (namely; Contrast adjustment, Sharpening, Decorrelation stretch, Histogram Equalization, and Adaptive Histogram equalization) and three denoising filters (namely; Median, Wiener, and Bilateral) were optimized their parameters on images of variety kidney pathology (i.e. stone, benign, and cyst) to have maximum PSNR and minimum MSE values. The best individual techniques for contrast enhanced was sharpening whereas for denoising Median and Weiner filters were better than others. The results of combination of denoising (first step) and contrast enhancing (second step), and in reverse order, showed that Bilateral filter causes to decrease PSNR (so, it increases MSE) in a wide range (it decreases the quality of the images). The unpredicted results were found while adding Bilateral filtered images with Sharpening contrast enhancement images (hybrid technique) which show high values of PSNR (so, small MSE). So, for images required for both demonizing and contrasting that cause enhancement the Bilateral filter which add with sharpening will give promise results.

Keywords: Contrast enhancement, Denoising filters, Hybrid techniques, Kidney abnormalities, MATLAB.

1. Introduction

Ultrasound imaging is so substantial for its optimal to another imaging technique for its safety radiation. It’s used for various purposes like detection of abnormalities and measurements of size and position [1].
Ultrasound images mostly suffer from speckle noises. So, image enhancing is substantial for any further consequent process such as diagnosing or segmentation of interested regions. It consists of contrast enhancement, edge sensing, and noise removal [2]. The proper enhancing techniques depend mainly on the kind of medical imaging instruments. Furthermore, image enhancement techniques divide into spatial and frequency domain. The first works on the pixel intensity and the other modifies the image coefficients that obtained from transformations such as Fourier and wavelet transforms. On the special domain enhancing methods is point operations that increase image contrast, so, it gives the more visual appearance of the image contents. Gamma correction and linear gray level are examples of point operations [3]. Histogram Equalization is another type of special domain which known as easy and efficient methods of image contrast enhancing. It works to regularly distribute the gray level of the image. It has further applications as voice recognition and texture analysis. This technique has also its drawbacks. First, it gives same gray level for two near pixel levels that have varying intensities. Secondly, it has washout effect through giving pixels high intensities. To improve this technique many techniques proposed in the literature. In 2012, Tan et al. [4] propose a technique named background brightness preserving histogram equalization. Here, image histogram separates to various levels and enhanced each one separately. So, the background image maintained during enhancing image. Khan and his coworkers [5] presented another based HE method which removes noises with enhancing images. They smoothed the image histogram then they separate it into multiple regions through using proper threshold gray levels and finally they enhance each region. Shah with other coresearchers [6] reviewed different methods of modified HE with determining improvement and drawback them. So, the researchers continuous their works to obtaining better enhance images with smaller drawbacks.

In the present work, five methods of contrast enhancement and three denoising filters will be applied individually and with each other, on the abnormal kidney that has solid, cyst or stone. Visual and objective evaluation will be used to comprise with other methods.

2. Materials and Methods

Four ultrasound images for each of kidney abnormalities (solid, cyst, stone) are studied in this work the data were taken from Hansen et all. work [7]. The type of abnormalities was indicated by the same reference.

The images were denoised (namely; Median, Wiener and Bilateral filter) and contrast enhanced (namely; Contrast adjustment, Sharpening, Decorrelation stretch, Histogram Equalization, and Adaptive Histogram Equalization) individually through optimized each parameter of them using PSNR variables for objective evaluation. The images also denoised then contrasted enhanced, in reverse order, and adding them, using mentioned techniques of enhancing.

The enhancement includes denoising and contrast techniques. The contrast enhances techniques performed through some operations like Point operations are referred to as gray-level transformations or spatial transformations. It can be expressed as:
\[ s = T[r] \] (1)

where \( r, T, s \) are the original gray level of a pixel, transformation function, and resulting gray level after processing. There is different point transformation such as linear (e.g., negative), nonlinear (e.g., gamma correction), and piecewise linear (e.g., gray-level slicing).

Contrast adjustment is most common applications of point transformation functions. The point transformation for 256 gray level (i.e. 8 bit) gives 0 and for darkest and 255 for brightest pixels, and it gives other intensities accordingly linear values of gray levels. So, contrast adjustment defined as:

\[ s = \frac{L-1}{r_{\text{max}}-r_{\text{min}}} (r - r_{\text{min}}) \] (2)

where \( r \) is the pixel value in the original image, \( r_{\text{max}} \) and \( r_{\text{min}} \) are the values of its brightest and darkest pixels, respectively, \( s \) is the resulting pixel value, and \( L - 1 \) is the highest gray value in the input image. MATLAB has built-in function `image` just to perform contrast adjustments.

Image Sharpening is another contrast enhancing technique that depends on edge detection. The edge constructs from pixels that varied sharply to higher or minimum of pixel values with respect to their neighborhood pixels. It computed through the image function behavior in the neighborhood. It is a vector which contains magnitude and direction. The edge magnitude is the values of the gradient, and the edge orientation determined according to the gradient direction \( \psi \) by 90°. The gradient magnitude \( |\text{grad} g(x,y)| \) and gradient direction \( \psi \) are continuous image functions calculated as:

\[ |\text{grad} g(x,y)| = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2} \] (3)

\[ \psi = \text{arg} \left(\frac{\partial g}{\partial x}, \frac{\partial g}{\partial y}\right) \] (4)

where \( \text{arg}(x,y) \) is the angle (in radians) from the x axis to the point \( (x,y) \). Sometimes one interested only in edge magnitudes without regarding to their orientations-so a linear differential operator called the Laplacian may then be used. It is defined as:

\[ \nabla^2 g(x,y) = \frac{\partial^2 g(x,y)}{\partial x^2} + \frac{\partial^2 g(x,y)}{\partial y^2} \] (5)

Image sharpening has the objective of making edges steeper, the sharpened image is intended to be observed by a human. The sharpened image \( f \) is obtained from the input \( g \) as:

\[ f = g - C.S \] (6)

where \( C \) is a positive coefficient which yields the ability of sharpening and \( S \) is a parameter shows the image function sheerness, which evaluated by a gradient operator like the Laplacian operator [8].

The RGB image can be enhanced by Decorrelation stretch technique through finding strongly correlated channels. So, one can see surface features of the true image more clearly. This may be done by increasing spectral difference of the image. The nine sums computed for the three channels of the image and used to finding covariance matrix. These sums are (for \( l=1-3; m=1-l \), and sampling \( n \) pixels):

\[ \text{SUM}_X_{l,m} = \sum_{k=1}^{n} P_{k,l} \cdot P_{k,m} \] (7)

\[ \text{SUM}_l = \sum_{k=1}^{n} P_{k,l} \] (8)
where $P_{k,l}$ is the value of the $k$th pixel for Channel $l$.

The covariance and the correlation matrices are evaluated according to following equations:

$$\begin{align*}
\text{Cov}_{l,m} &= \frac{1}{n-1} \left( \text{SUM}_X_{l,m} - \frac{1}{n} \text{SUM}_l \cdot \text{SUM}_m \right) \\
\text{Corr}_{l,m} &= \frac{\text{Cov}_{l,m}}{\sqrt{\text{Cov}_{l,l} \cdot \text{Cov}_{m,m}}} 
\end{align*}$$

The correlation matrix (or optionally covariance matrix) used to obtain eigenvectors and eigenvalues. The eigenvectors named here as Rotation matrix, $\mathbf{R}$. The inverse of square root of each eigenvalue vector multiplied by standard deviation called the stretching vector, $\mathbf{s}$. So, the transformation operator $\mathbf{T}$ is computed as follow [9]:

$$\mathbf{T} = \mathbf{R}^t \mathbf{s} \mathbf{R}$$

Histogram Equalization is another well-known enhancement techniques. In this enhanced method, the contrast and dynamic range changed by changing the shape of intensity histogram. This changing obtained by employing cumulative distribution function (CDF) as the mapping function. If a digital image has $N$ pixels distributed in $L$ discrete intensity levels and $n_k$ is the pixel numbers with intensity level $i_k$ then the probability density function (PDF) of the image is given by Equation below. The next equations utilized to get cumulative density function:

$$\begin{align*}
f_i(i_k) &= \frac{n_k}{N} \\
F_k(i_k) &= \sum_{j=0}^{k} f_i(i_j)
\end{align*}$$

This technique of enhancing is simple due to clear separating gray levels from each other. This causes to some poor qualities of the image [10].

Adaptive Histogram Equalization (AHE) also work as contrast enhanced method and it obtained by using several histograms for the various regions of the image. So, it differs from Histogram equalization. AHE enhance local contrast, so one can see further details of the image. This technique also has disadvantages such as it increases the noises with increasing contrast [11].

The median filter is a method of denoising image with preserving edges. It is a particular case of local histogram filter. The mean magnitude is put into the pixels that needs for modification. Its properties of denoising with maintaining edges are better than linear smoothing filter [12].

Wiener filter also is a type of denoising filter which works to get the optimum linear filter for estimation of a wanted signal sequence from another related sequence. The mechanism of reducing noise in this filter is done by comparing it with an estimation of the desired image without noise. This filter is a stationary linear filter which optimized for mean square error of images that added it to noises or blurs. It works in the frequency domain by using Fourier transform. The filter is more proper for blur image that comes from unfocussed optics or from linear motion.

The Bilateral filtering is a smoothing with maintaining the edge of the image. It obtained by adding two Gaussian filters. the first used for filtering spatial domain, and the other for intensity domain. so, it is a nonlinear filter that obtained by a weighted mean of the input. The bilateral filter for a pixel evaluated using following equation:
\[ J(s) = \frac{1}{K(s)} \sum_{p \in \Phi} (p - s)(I_p - I_s)I_p \]  
\[(14)\]

Where \( K(s) \) is a normalization term:

\[ K(s) = \sum_{p \in \Phi} f(p - s)g(I_p - I_s) \]  
\[(15)\]

Where \( f \) uses a Gaussian in the spatial domain which represents the domain filter and \( g \) uses a Gaussian in the intensity domain which represents the range filter [13].

3. Results and Discussion

Four Ultrasound images used in this study that diagnosed as simple cyst, cystic-solid, solid, and stone (see Fig. 2).

Each image cropped manually to have just region of interest then optimize parameters for each enhanced method. The optimizations were done according to well-known objective parameters which are MSE and PSNR. Five types of contrast methods used here, namely; Contrast adjustment, Histogram equalization(HE), Adaptive Histogram Equalization (AHE), Image sharpening, Decorrelation stretch, and three of denoise enhancing, namely; median filter, wiener filter, Bilateral filter.

The results of MSE and PSNR for the four images and for all enhanced methods are shown in Fig. 1. It’s clear that sharpening and Wiener filter are best than other contrast and denoise enhancement methods, respectively. So, the output images for the four cases for those are best which mentioned as shown in Fig. 2. The worth was HE and Bilateral filters for the two types of enhancement. It is hard to see the difference between origin and enhanced images according to visual perception.

Figure 3 shows charts of mean with standard deviation for MSE and PSNR for the four cases after denoising then apply contrast enhancement (a,b), in reverse order (c,d), and adding two steps (e,f). It is clear from the Figs. 3 (a, b) that better results of enhancing was for wiener filter and sharpening techniques. Same results were found (see figs. 3 c-d) if reversing the order of mentioned enhancing. The worst quality of previous the two orders was contrast techniques with Bilateral filter. Figures 3 (e,f) show best results than the mentioned orders of enhancing when adding Bilateral filter with sharpening technique. The contrast enhancing with wiener and median filter gave worst results. So, the output images of two added stage mentioned as best enhancing are shown in Fig. 4. Their values of MSE and PSNR is represented in Table 1 shows individual and different order of better enhancing methods for the four cases of Ultrasound images.

4. Conclusion

Ultrasound images usually need denoising and contrast enhancement. From three denoise filters and five contrast enhancement; after optimizing each one according to objective evaluation MSE and PSNR parameters, one concludes that image sharpening and Wiener filter are best, and lowest were HE and Bilateral filter when individual techniques used. However, when both denoise filters and contrast enhancement methods used as series steps, i.e. contrast following denoising or in reverse order, Wiener filter then applying Sharpening gives better results than different other denoise filters and contrast enhancements.
Best and unexpected results found when adding Bilateral filter with Sharpening contrast enhancement. The worth of using two types of enhancement in the sequence were all contrast enhancement followed Bilateral filter.

Acknowledgement

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References


Table (1) Represents individual and different order of better enhancing methods with objective evaluation parameters MSE and PSNR for the four cases of Ultrasound images.

<table>
<thead>
<tr>
<th>Techniques and Parameters</th>
<th>Stone</th>
<th>Simple Cyst</th>
<th>Cyst-Solid</th>
<th>Solid</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contrast Technique</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>MSE</td>
<td>5.82E-06</td>
<td>6.28E-06</td>
<td>5.50E-05</td>
<td>3.69E-06</td>
<td>1.77E-5±2.49E-5</td>
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<tr>
<td>PSNR</td>
<td>100.4</td>
<td>100.2</td>
<td>89.8</td>
<td>102.3</td>
<td>98.18±5.6</td>
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<tr>
<td><strong>Denoise Technique</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSE</td>
<td>4.6</td>
<td>4.3</td>
<td>5.2</td>
<td>1.6</td>
<td>3.93±1.59</td>
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<tr>
<td>PSNR</td>
<td>41.4</td>
<td>41.8</td>
<td>39.8</td>
<td>45.9</td>
<td>42.23±2.5</td>
</tr>
<tr>
<td><strong>Denoise then Contrast Technique</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>MSE</td>
<td>4.5</td>
<td>4.2</td>
<td>7.1</td>
<td>1.6</td>
<td>4.35±2.25</td>
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<tr>
<td>PSNR</td>
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<td>41.9</td>
<td>38.6</td>
<td>46.1</td>
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<tr>
<td>MSE</td>
<td>4.2</td>
<td>4.4</td>
<td>5.8</td>
<td>1.6</td>
<td>4.0±1.75</td>
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<td>39.3</td>
<td>45.8</td>
<td>42.08±2.7</td>
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<td><strong>Denoise add Contrast Technique</strong></td>
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<td>MSE</td>
<td>0.22</td>
<td>0.20</td>
<td>0.29</td>
<td>0.25</td>
<td>0.24±0.03</td>
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<tr>
<td>PSNR</td>
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<td>55.1</td>
<td>52.6</td>
<td>53.9</td>
<td>54.05±1.0</td>
</tr>
</tbody>
</table>
Figure (1): Shows PSNR and MSE values versus different contrast and denoising enhancement techniques for four cases of ultrasound images.

Figure (2): Shows the four cases under study for best denoise (Wiener filter) and contrast (Sharpening) enhancement according to the results of Fig. 1.
Figure (3): show charts of MSE and PSNR for (a,b) Denoise then Contrast (c,d) Contrast and Denoise and (e,f) adding two types for the four cases: simple cyst, cystic-solid, solid, and stone.
Figure (4): Shows origin image (first column) and enhancement of the four cases (second column) when it added Bilateral filter and Sharpening due to their lower MSE and higher PSNR as seen in Fig. 3.