Noise Reduction and Kidney Ultrasound Image Enhancement Based on Multi-Scale Transform and Curvelet Transform

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Abstract

A new algorithm for contrast enhancement and noise removal from the ultrasound images is proposed. At first, Sticks filteris used to remove the initial noise from the ultrasound images. Then the image brightness is improved. Finally multi-scale and new generation of curvelet transform, the coefficient adaptive correction of these transforms, non-linear modificationand adaptive functions suggested here are applied to enhance the final contrast and removing any noise from the kidney ultrasound images.
Key words:noise removal;contract enhancement; curvelet transform

1. Introduction

Medicinal imagingplays an important role in diagnosing and preventing organdiseaseslike brain, heart and kidney, in the recent years. Ultrasound imaginghas many advantagesover the similar systems, such as X-ray, MRI, and CT imaging, e.g. Lack of any disturbances,repeatability in any numbers, 3-D images and lack ionization effect. These advantages increase therange of ultrasound imaging applications in various medicinal fields.Ultrasound images have some limitations and disadvantages, which the main ones are that they are noisy and low quality. Therefore, Noise reduction and image enhancement are often the initial step in the ultrasound images processing.In [1], Savitzky-Golayfilteris used for ultrasound imagenoisereduction. It is assumed that the image pixels intensity isa random Markov variable. Using a special order for the reformation leads to more noticeablecorrelation between the neighboring elements in the result vector that makes possible the image information to present with low order polynomials.In [2], commonmean filter is used for this purpose. In [7**]** simplemedian filter isapplied**.** Thelimitation of this method is loss of sight to the image and its noise contents. In [9], wavelet coefficient correction is used to remove the noise of the images. ButBecause of the weakness in the present wavelet tool, all the features and information of the image in all possible directions and frequenciesmay not extract. Therefore, this tool would not be able to determine the noise from the image information and effectively remove it from the image.

In the proposed algorithm the new generation of curvelet transform is usedto improve the kidney ultrasound images and removing their noise.Anon-linear function is suggested in order toimage contrast enhancementand noise reduction. The curvelet transform is chosen because of its capabilityfor edge detection with the least number of required coefficients in the curvelet space. The performance of the proposed method is compared with the other similar multi-scale ones like the wavelet.

2. Materials and Methods

In this article, 50 kidney ultrasound images with300×300 pixels obtained from the radiology unit of Shariaty Hospital, Isfahan, Iran [11] have been used.The kidney borderline in all images is determined by the radiology specialists.Inthe proposed algorithm the pre-processing step is applied on the image to improve the kidney ultrasound images quality. Since ultrasound images usually contain extremely intrinsic noise, the noise removal without image information loss is performed in two steps usingsticks filter in [8,3]. Then, equalizing brightness filter [4] is used to equalize the brightness changes all over the image. In the next step the curvelet transform[5] is applied on the kidney ultrasound images. Finally in order to more noise reduction, the curvelet coefficients are corrected withan adaptive correction function[6].Coefficients correctionwith the proposed method is performed such that beside noise reduction, improves the images contrast and by considering statistical parameters of the coeficients, not only greatly removes the speckle noises, but also by signal detection prevents the useful images information loss.

3. Pre-Processing

3.1.Multi-Directional Sticks Filters

Sticks filters [8,3] are first introduced in 1998 by Czerwinski[8].These filtering are based on window-filtering in which despite the spatial filters with single window(e.g.the mean filter with the same value of$1/L^2$when its size is L×L pixels), use several masksin multi directions. For a Sticks filter with the sizeofL×L ,there are 2L-2possible states for linear directionmasks. If $S = \{s_{\theta_i} | i = 1,2,\cdots,2L-2\}$ is denoted as the masks sets, the i^{th} mask is defined:

$$s_{\theta_i}(x,y) = \begin{cases} \frac{1}{L} & (x,y) \in \theta_i \\ 0 & otherwise \end{cases} \qquad (1)$$

Where θ_i is the area of directionnumber i, and L is the mask length. Each Sticks Mask really is a mean filter around direction θ_i.

Fig.(1) shows these possible masksfor L=5. In this figure the white and black spots have the values of 0 and 1/5, respectively.

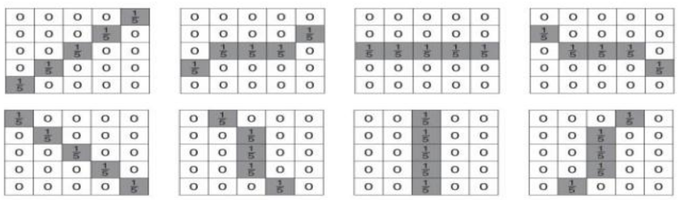


Fig1:Different masks of the Sticks filter with L=5

As there are 2L-2 masks, the results of applying Sticks filters on the main image$f$ will be 2L-2 image [8]. If $H = \{h_i | i = 1,2,\cdots,2L-2\}$ is denoted as the resulted image, in which $h_i = f * s_{\theta_i}$. Finally, the output filtered image$g$ is obtained in a pixel-to-pixel comparison between produced images and selection of maximum value. In other words:

$g(x,y) = \max_i h_i(x,y)$ (2)

The above filter reduces spot noises andcauses the lines of the original image in different directions to be brightened. In this algorithm, Sticks filters are used in two consecutive steps in order to remove the initial noise. In the first step,a filter with length 5 and thickness of 3 and in the second step a filter with length 15 and thickness of 1 are used.More lengths of the applied mask in Sticks filter, produces more clear image, and more thickness of the mask results more noise removal.

3-2- Brightness Correction of the image

By local applying of the function introduced in [4] on all the individual pixels of the gray area of the images, the unexpectedseriousbrightnessvariations over the images are considerably reduced. In this process,the equalized brightness of each pixelsin the location of (i,j) with original value of $I(i,j)$is given by:

$I_{eq}(i,j) = I(i,j) + \mu_{desired} - W_\mu(i,j)$ (3)

Where$\mu_{desired}$ is the desired mean brightness and $W_\mu(i,j)$ is the actual mean brightness intensity corresponding to the window located in(i,j).

4.Noise Removal and Contrast Enhancement

4.1.Curvelettransform

Curvelet transform [5] causes a group of coefficients in different direction and scales by applying a certain wavelet in different scales and direction on the main image. Any of these coefficients sets locate in polar wedges reveal the information of the image in that special scale or direction.The curvelet coefficients are provided from the following relation:

$$C(j,l,k) = \frac{1}{(2\pi)^2} \int f(\omega) U_j (R_{\theta l} \; \omega) e^{i \langle x_k^{(j,l)}, \omega \rangle} d\omega \quad (4)$$

Where f is the Furrier transform of the signal, and U_j is the applied window-frequency in the frequency domain, .U_j is in fact a collection ofpolar wedges which both radial and angular covers the image. $R_{\theta 1}$ is the rotation equal to θ1 radian and is defined as:

$$R_{\theta_l} = \begin{pmatrix} Cos\,\theta_l & Sin\,\theta_l \\ -Sin\,\theta_l & Cos\,\theta_l \end{pmatrix} \quad (5)$$

And in this way, the C(j,l,k) is obtained where j,$l$and k are the scale, direction and translation parameter, respectively.x is the spatial-domain variable, ω is the frequency domain variable , and R and θ are the polar coordinates in the frequency domain.Fig(2) shows the curvelet tiling in the frequency domain.

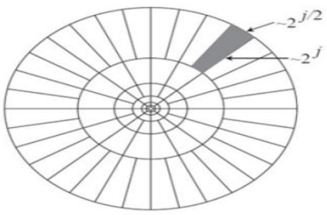


Fig2.Curvelet tiling in the frequency domain

Curvelets in the frequency domain covers a parabolic wedge. The shaded area represents such a generic wedge.

4.2. Curveletcoefficients correction adaptive function

According to the definitions of the function parameters based on the statistical feature of the input image curvelet coefficient, if the following adaptive function is applied on the coefficients of the equalized intensity image, then the function works adaptively, and can adapt with applying any input image and based on its curvelet statistical coefficients. The proposed adaptive function in this articleis obtained as the following:

$$y(x) = \begin{cases} k1(\frac{m}{c})^{p} & \text{if} \quad |x| < ac \\ k2(\frac{m}{|x|})^{p} & \text{if} \quad ac \le |x| < m \\ k3 & \text{if} \quad m \le |x| \end{cases} \tag{6}$$

Where p determines the non-linearity degree, and k_1, k_2, and $k_3$are the coefficients and *m* is defined as the followings[10]:

$$m = k(M_{ij} - \sigma) \tag{7}$$

Where M_{ij} is the biggest coefficient in the given direction and scale, and it shows that the coefficientsare improvedbased on their own maximum values. C=σ is the standard deviation of estimated noisefrom image, whileamplifying the favorite signal it prevents the noise increased [10]. C and M_{ij}parameters cause the above function to operate adaptively and adapt with different input images. The above function increases the lower coefficients more than the biggerones . The influence of this function on the coefficient is a local one, that is, M_{ij} is separately measured in each special direction and scale and the mentioned function is applied on the coefficients of the same polar wedge (a frequency band with special orientation and scale) which it leads to more influences on the image.

5. The Results of Performing

5.1.AlgorithmEvaluation Parameters

The quantitative evaluation of the contrast improvement of the kidney ultrasound images in the proposed algorithm is performed with the peak signal-to-noise ratio (PSNR), and it is done on all the present images of the data bank. The relations regarding to PSNR ratio is shown in relation.

$$PSNR = 10 \log_{10} \frac{Max_I^{\,2}}{MSE} \tag{8}$$

Where Max_1 is the highest brightness of the image, and MSE is the mean square error, which is defined as (Eq.12) :

$$MSE = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} \left\| I_O(i,j) - I_e(i,j) \right\|^2 \tag{9}$$

Where I_0 is the initial image and I_e is the enhanced one. In order to evaluate the noise removal ability of the proposed algorithm , four popular criteria are applied. All these criteria compare the initial images and the final noise-removed ones, and they evaluate the efficiency of the proposed algorithm. PSNR algorithm and MSE, which were explained before, measure the enhancement of the image quality while they are used as those criteria to evaluate the efficiency of the noise-removing algorithm. The third criterion is SNR which explains the ratio of the signal variance power of the noiseless image to that of the initial noisy one. The relation of this criterion is explained as the followings:

$$SNR = 10\log_{10}\frac{\sigma_s^2}{\sigma_n^2} \tag{10}$$

Where δ_s^2 and δ_n^2 are the variances of the noiseless and initial noisy images, respectively.
The forth criterion is RMSE which explains theroot mean square error and its relation is

defined as:

$$RMSE = \sqrt{MSE} \tag{11}$$

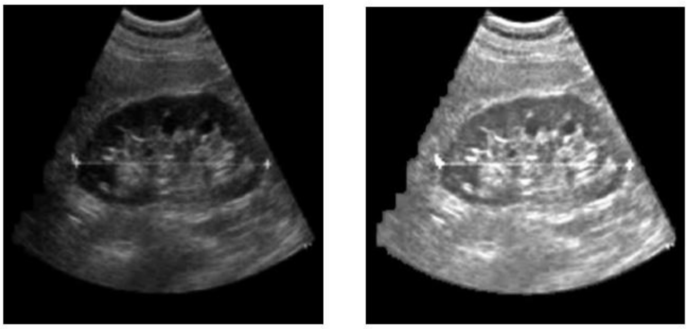
5.2. Pre-processing

As noted earlier, all the images in the data center are resized to 300×300 pixels. The present labels in the main images are removed in order not to have a bad influence. As noted, sticks filter removes the noise of the main image in the pre-processing step .Here , sticks filter is used in two steps to remove the noise and smoothing. In the first step, a sticks filter with L=5 pixel and the thickness of 3 pixel is used , while in the second one, the 15 and 1 pixel are used, respectively. The more the length of the masks applied in sticks filter, the smoother the filtering , and the more the thickness of the masks, the better the noise removal.

Through applying the brightness correction function in the pre-processing step on the kidney ultrasound images, their quality will be greatly improved. To do so a window with the size of 8×8 pixels and µdesired=127 was applied and experiments showed that larger radius leads to the destruction of the image and smaller ones have no sensible effects. Fig (5) shows the results of the pre-processing step on the sample ultrasound image present in the data center. As we can see, moreover the equalizing of the image brightness in pre-processing, its Speckle noise has also greatly decreased.

(a)(b) **(c)**

Fig .3:a) Main image .b) The mask removing the interfering labels of the image .
c) Label-removed image and resized to 300 ×300 pixel



(a) **(b)**

Fig.4: a) The image of applying two Sticks Filtering steps. b) The image obtained from applying equalizer intensity filter. PSNR = 36.9

5.3. Contrast Enhancement and NoiseRemoval

In order toperform thecurvelet, 5 bands were used in which the images are analyzed with different scales. Th**e** angular accuracywas selected about 22.5º in the first scale, that is ,considering 16 directions in the first scale . Then by applying the proposed adoptive functions , the extracted coefficients from the image are corrected to remove noise and final contrast enhancement, which after several experiments , the adaptive function parameters of the following were obtained:

A=1, p=0.3, k=1, k_1= 0.85, k_2=1, k_3=1.1

Fig(5)illustrates the generated image of the contrast enhancement and final noise-removal stages.

Fig.5:Final noise-removed image with SNR=33.91 , PSNR=39.3, SNR=33.91, MSE=7.64, RMSE=2.76

The mean value andstandard deviation from the PSNRare separately depicted in Table 1.

Quantitative Standard	Mean Value	Standard Deviation
PSNR	34.76	1.01

Table 1.The results of the image improvement of all the available images in data center resulted from the pre-processing step

In scientific articles, the PSNR values of 30 and more are considered suitable which shows the noise being removed successfully . This value also depends on the kind ofthe under-studyimage. As we can see in Table 1, the proposed methods of this article could achieve to this value, and not only it prevents the noise amplification , but also has greatly increased the contrast of the ultrasound images.The standards of algorithm evaluation for all the available images in the data centre were calculated , and the results are shown in Table2.

Algorithm	SNR	PSNR	MSE	RMSE	Run Times
Our Algorithm	32.2	38.59	9	3	4

Table2. The results of noise removal and contrast enhancement in the kidney ultrasound image for all the available images in data center

As we can see, the proposed algorithm is able to greatly remove the noise of the kidney ultrasound images. It's worth mentioningthat through utilizing MATLAB software and a normal computer withDual core 2.6 GHz CPU and 4GB RAM to run the proposed algorithm, the simulation time of second was obtained which is moresuitable than the other similar works. It's necessary to say that by running this algorithm in C++ language , the simulation time is decreased 15 times which makes this algorithm scientifically practical in clinics.

6. Conclusion

Based on the offered criteria for evaluating the performanceof the enhancement algorithm of the image contrast and noise removal of the kidney ultrasound images ,we can say that this suggested algorithm has a suitable success to achieve this goal. Performing twoSticks Filtering led to initially removal of the noise in kidney ultrasound imageswithout removing useful information . Applying brightness correction function on the images greatly uniformed the brightness of the images and it had a great role in improving the quality of the final images. Considering the mentioned features for the Curvelet transform, it was seen these advanced tools, is greatly effective in contrast improvement and on the other hand proper selection of correction function and suitable adjustment of its parameters led to the contrast improvement and noise amplification prevention. In addition to these advantages, considering its performing time is also important . This proposed algorithm not only has a great efficiency in the noise-removal stage but also has a great and suitable performing time. As mentioned before, by performing this algorithm in C++ language the simulation time can be reduced to 15 times , which make the algorithm s practical and ideal for the clinics.

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