An Algorithm for Medical Ultrasound Image Enhancement by Speckle Noise Reduction

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Abstract: Medical digital images and medical image processing represent an important subfield in computer vision. Different algorithms and methods for analysis and improvement of various medical images were proposed in the past years. One important research topic is improvement of ultrasound images. In this paper we propose a modified median filter with adaptive size for removing one of common noise in ultrasound medical images, speckle noise, including the case when spots are larger than one pixel. Proposed method was tested on different ultrasound images and different evaluation metrics used as measure of the quality of noise removal have shown that the proposed method was successful.

Key–Words: Ultrasound medical images, speckle noise, denoising, median filter.

1 Introduction

In recent decades, digital images are very widely used. They are used for transmission of visual information and represent one of the main methods of communication today. Large number of application include digital images such as handwritten digit recognition [1], lip detection [2], multilevel image thresholding [3], [4], etc. Image compression and enhancements are also popular research topics [5], [6]. One area in which digital images spread to a large degree is medicine. Digital images for medical purposes are obtained from various sources, like ultrasound images, magnetic resonance [7], etc. Different images are used for different purpose. Ultrasound images are very popular manly because ultrasound is not invasive, inexpensive and it produces real time images. The internal parts of the body, such as tendons, muscles, joints, vessels and internal organs can be seen using ultrasound images. In most cases the goal of diagnosis using ultrasound image is to find a source of disease, or to eliminate any pathology. Ultrasound images are images of poor quality. They can be affected with different degradations. One of typical degradation is appearances of some kind of noise.

Various types of noise can be presented such as amplifier noise, impulsive noise and speckle noise. A typical representative of the amplifier noise is Gaussian noise [8]. This noise is independent on each pixel and each signal intensity. For example the blue channels can contain more amplitude than the red and green channels, which means that the blue channels can have more noise in the color cameras. Impulsive noise, or as otherwise referred to as salt-and-paper or spike noise is most frequently occurring noise in images [9]. This noise in the image is shown by the white and black pixels and if the image is contaminated with impulsive noise, in the darker areas in the image will appear white pixels, and on the lighter areas black pixels will be shown. Speckle noise is a granular noise [10]. One of the areas where it appears often is ultrasound images. This paper deals with this kind of the noise, thus it will be explained in more detail in one of the following sections.

To eliminate noise various techniques were used. In general, noise removing algorithms can be categorized in one of the following types of noise reduction techniques: spatial filtering [9], transform domain filtering and wavelet based thresholding [11]. In this paper, spatial filtering is presented. This types of algorithms can be divided into two categories, linear and non linear filtering. Linear filtering include linear filters, mean wiener filters and others, while one of non linear filters is a median filter.

As mentioned before, depending on the choice of domain filtering is divided into spatial, frequency filtering and wavelet domain filtering. Algorithms in wavelet domain are a signal estimation technique that exploits the capabilities of wavelet transform for signal denoising. Wavelet thresholding methods are thresholding based methods, with threshold selection rules. Non adaptive threshold and adaptive threshold are also variants of thresholding techniques.

In this paper ultrasound image denoising method in spatial domain is presented. Method for removing speckle noise on ultrasound images is proposed and tested on images of different organs. Quality of proposed algorithm is measured with several metrics.

In Section 2 literature review of the techniques and methods that are applied in ultrasound images is presented. The section 3 presents the general review of the noises at ultrasound images. Section 4 describes the proposed algorithm for removing noise from ultrasound images. We used median filter for removing speckle noise. Section 5 contains the results obtained by our proposed method. At the end, Section 6 gives conclusion.

2 Literature Review

Ultrasound images are widely used in medicine for diagnostic, determination of appropriate treatment and others. Quality of the ultrasound images is very important. Improving ultrasound images for different proposes is subject of research papers for many years. Different algorithms for improving images in different ways were presented.

In paper proposed by Fontes et al. [12] modified non local means method for removing noise was presented. this method was proposed to be used in real time. Graphic implementation of the algorithm was also presented. The results of this method shows that it has potential in the denoising in real time.

Sheng et al. in [13] presented denoising method based on edge signal detecting and MMSE estimation in non subsampled contourlet transform (NSCT) domain. In the edge zones and flat zones of signal, high frequency in NSCT subbands are located. In NSCT domain, multipicative speckle noise of ultrasound image was derived and Bayesian minimum mean square error estimation by noise reduction of filtering equation. At the end, inverse NSCT performs the reconstruction of the denoised image by applying denoised coefficient. This method overcomes several traditional methods for denoising medical image when it comes to speckle noise and detail preservation of informations.

Bhonsle et al. in [14] uses bilateral filter added to the image infected with Gausian noise. This nonlinear and local method was used in ultrasound images which have a Gaussian noise and preserves the features as smooting image. The result was effectively removing Gausian noise and less successful removing of salt and paper noise.

Guided filter was used by Kaiming et al. in [15]. This filter was originated from the local linear model, create the output bearing in mind the guided image. It can act as a bilateral filter, but fares better near the edges. Guided filter was shown as effective in a computer vision and graphic applications.

In [16] Devarapu et al. curveled transform was used. Curvelet based denoising algorithm was performed better at protecting the edges of the ultrasound images than other techniques that apply adaptive filters and some other filters.

Ai et al. in [17] used multiresolutian generalized dimension N PCA method. Gaussian pyramid and multiscale image stacks on each level we re built into this method. They combine all levels in order to get denoised image that relies on Laplacian pyramids. There were used ultrasound and synthetic noise in combination with the aforementioned method in order to assess its performance.

3 Ultrasound Image Noise

The technique for diagnosing that uses ultrasound images is one of the most popular in today's time. Every day, more and more techniques for processing of ultrasound images are proposed. Some of them are methods for segmenting anatomical parts from ultrasound image like those for segmenting the prostate, tumors in the breast, the carotid artery, and the thyroid nodule. Ultrasound technique is accessible in terms of cheapness and use. It does not require the use of radiation for the purpose of treatment [18] which make this technique popular .

Several modes of ultrasound are used in medical imaging. A-mode or amplitude mode where transducer scans through the body and depending on the depth of scanning creates echo that graphically represents on the screen. B-mode or 2D mode (brightness mode) where linear transducer performs simultaneous scans through the body and produces a two-dimensional ultrasound images. Another mode is C-mode.In this mode image is obtained in a plane perpendicular to the B-mode image. It choose data from a certain depth A-mode lines. Then transducer is moved in 2D plane and scanned the entire region at a fixed depth. M-mode also called motion mode is one of the modes of ultrasound images. In this mode, the pulses are appearing one after the other at short intervals taking either A-mode or B-mode image.

Doppler mode (also known as color doppler, continuous doppler, pulsed wave doppler, duplex) where visualization and measurement of blood flow is carried out by means of Doppler effect.

In pulse inversion mode two consecutive pulses of different characters that are emitted and then subtract each other are taken in consideration.

Harmonic mode images are obtained when deep penetration frequencies that are emitted into the body and detected by the harmonic overtone.

Ultrasound images are used in many field of medicine. All this different modes of ultrasound images allow various use of them. However, one of the main issues with this kind of images is bad quality.

Bad quality of images is major disadvantage of ultrasound images in different modes. Usual reason for bad quality is some kind of noise. Earlier were mentioned different types of noise that are presented on ultrasound images. One of the noises that is common for ultrasound images is speckle noise.

Speckle noise is granular noise. It reduces the quality of the active radar, synthetic aperture radar (SAR), ultrasound images and tomographic images. This noise reduces the possibility of better review of medical tests shown on the ultrasound image. Speckle noise changes the structure of the image, weakening it and thus minimizing the possibility of its processing [19]. Speckle noise is presented as white and black pixels over the image. Some amount of pixels is affected by this noise and pixel's values are incorrect.

The mathematical formula for speckle noise with the gamma distribution:

$$F(g) = \frac{g^a}{(a-1)!a^\alpha} e^{-\frac{g^2}{a}} \quad (1)$$

Where a^2 is the variance, α is the shape parameter of gamma distribution and g is the gray level. In this paper we applied this noise on original images and tested proposed method of denoising.

4 Proposed Algorithm

Speckle noise is one of the most common noise on ultrasound images. In this paper we propose method for removing this kind of noise. Median filter algorithm for removing the speckle noise from the ultrasound image is proposed. Median filter is one of the techniques for removing speckle noise and it can be adjusted and applied with the ultrasound images. In general, this is local filter where $n \times n$ mask is applied over the entire image. In this paper we used mask size 3×3. Central pixel of the mask (pixel with the index (2,2)) is determined. Central pixel is set on median value of pixels from the mask [20], [21]. In order to make the filter sensitive to larger areas affected by noise where 3×3 mask may not be sufficient to remove such defects simply by using median we included dynamic adjustment of the filter size depending on the detected defects. Formally, median filter can be written as following:

$$f(x,y) = median_{(s,t)\in S_{xy}}\{g(s,t)\} \quad (2)$$

where S_{xy} is the set of coordinates in a rectangular sub image window, centered at point (x, y), and median represents the median value of the window.

The application of the proposed method can be described as following. The first step is to take an ultrasound image. The second step is to add speckle noise according to Eq. 1 to the original image. Then in the third step should be to remove the noise which has infected ultrasound images. In our paper we use the median filter formula presented in Eq. 2 for removing the noise. Fourth and the last step shows the results that were obtained by removing noise, and then we compare the results with the original image that was used in the first step.

After the implementation of the chosen method for removing the noise from ultrasound image, there are some methods for testing the performance of this algorithm. These methods include different types of error measurements. Some of them are: MSE (Mean Square Error) PSNR (Peak Signal to Ratio), NK (Normalized Cross Correlation), AD (Average Difference), SC (Structural Content), MD (Maximum Diference), NAE (Normalized Absolute Error) and IEF (Image Enhancement factor). Definition of this measurements are given next.

$$MSE = \frac{1}{NN} \sum_{i=1}^{N} \sum_{j=1}^{N} (x*_{i,j} - x_{i,j})^2 \quad (3)$$

where $x*_{i,j}$ represents the original image, and $x_{i,j}$ represents the restored image. For peak to signal noise ratio (PSNR) mathematical equation is presented by:

$$PSNR = 10 \log \frac{65025}{MSE} \quad (4)$$

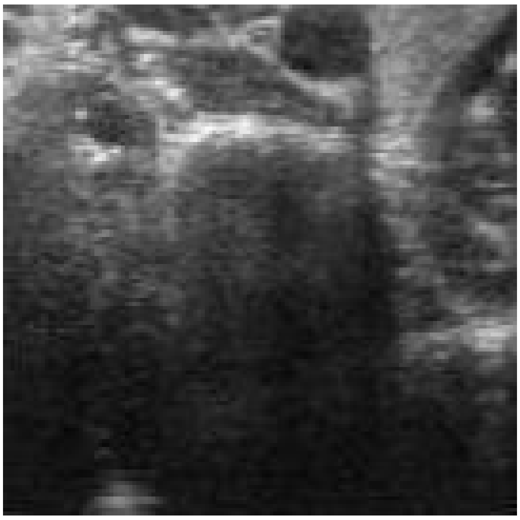
Normalized cross correlation (NK) is defined by following equation:

$$NK = \frac{\sum_{i,j}^{N} \sum_{i,j}^{N} x*_{i,j}\, x_{i,j}}{\sum_{i,j}^{N} \sum_{i,j}^{N} x*_{i,j}^2} \quad (5)$$

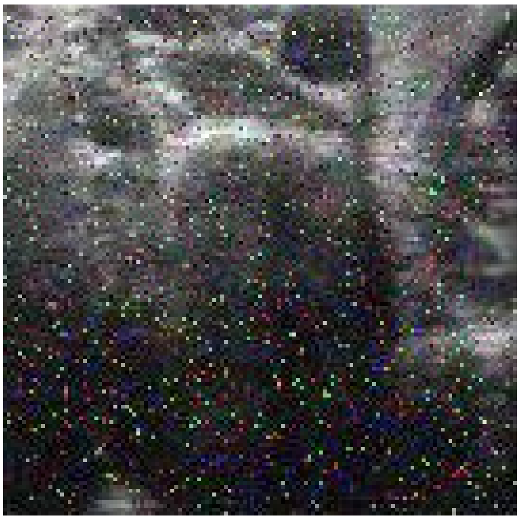
Average difference (AD) can be calculated by next equation:

$$AD = \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} (x*_{i,j} - x_{i,j})}{NN} \quad (6)$$

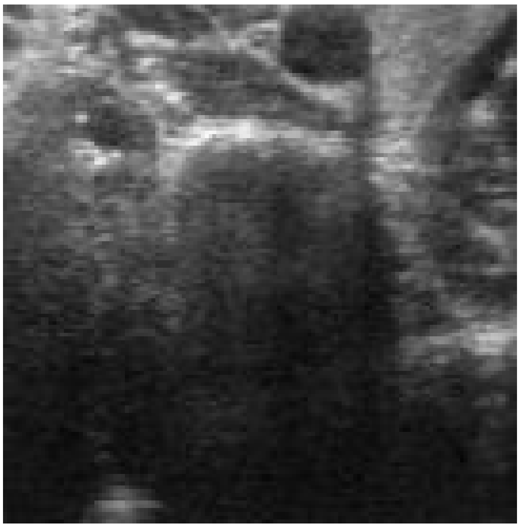
where $x*_{i,j}$ represents the original image, and $x_{i,j}$ represents the denoised image. The equation for Structural content (SC) is presented by:



(a) Original



(b) Noise



(c) Denoised

Figure 1: Ultrasound images of neck

$$SC = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} x_{i,j}^2}{\sum_{i=1}^{N}\sum_{j=1}^{N} x*_{i,j}^2} \quad (7)$$

Maximum difference (MD) equation is:

$$MD = \max(|x*_{i,j} - x_{i,j}|) \quad (8)$$

Normalized absolute error (NAE) equation is:

$$NAE = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} |x*_{i,j} - x_{i,j}|}{\sum_{i=1}^{N}\sum_{j=1}^{N} x*_{i,j}} \quad (9)$$

Image enhancement factor (IEF) equation is:

$$IEF = \frac{NoisyImage - OriginalImage}{DenoisedImage - OriginalImage} \quad (10)$$

This metrics were used to test the quality of the proposed method.

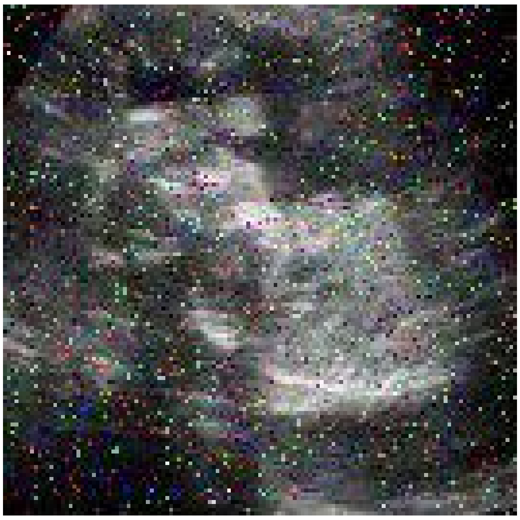
5 Experimental Results

In our paper, ultrasound image denoising method experiments were performed on the computer with Intel ® Core^{TM}i5-2410M CPU at 2.30GHz, 4GB RAM, Windows 10 Home OS. Implementation of proposed algorithm were done using MATLAB (R2015a) software. Ultrasound images used in this paper are taken from the paper [22]. In Fig. 1 original ultrasound image of neck, image with the speckle noise and image after denoising are shown. Fig. 2 presents original image, image with the noise and denoised image of ultrasound scan of the stomach. As it can be seen, with our proposed method, speckle noise is almost completely removed. This can also been seen from earlier defined metrics for quality estimation. Calculated metrics for evaluation method used in this paper are presented in Table 1.

Table 1: Calculation of evaluation metrics

Evaluation metrics	**neck**		**stomach**	
	with noise	denoised	with noise	denoised
MSE	1141.3	43.4371	1160.9	136.0055
PSNR	17.5568	31.7522	17.4830	26.7952
NK	1.0170	0.9832	1.0108	0.9687
AD	3.2834	0.4655	2.9513	1.1873
SC	0.8231	1.0274	0.8443	1.0454
MD	243	101	255	110
NAE	0.0947	0.0601	0.0918	0.0866
IEF	-	1.6527	-	1.0295

(a) Original



(b) Noise

(c) Denoised

Figure 2: Ultrasound images of stomach

6 Conclusion

In this paper we proposed a method for removing speckle noise from the ultrasound images. We used a modified median filter and the method has been tested using standard bencmark ultrasound images. It has been shown that the proposed modified median filter can be used to successfuly remove speckle noise from the ultrasound images. Different quality measures were used to assess the quality of the proposed method.

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