Medical Ultrasound Image Speckle Noise Reduction by Adaptive Median Filter

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Abstract: Medical ultrasound is a powerful nonivasive diagnostics tool. Due to physical factors of the diagnostics system, ultrasound generated images usually contain some noise where specle noise is often a prominent component. In this paper we propose an adaptive median filter with adaptive window size for removing speckle noise from ultrasound medical images, including the case when spots are larger than one pixel. Our proposed algorithm was tested on different ultrasound images and different evaluation metrics including mean square error, peak signal to ratio, normalized cross correlation, average difference, structural content, maximum difference, normalized absolute error and image enhancement factor were used as measure of the quality of noise removal. All these metrics 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 were widely used. They are used for transmission of visual information and represent one of the main methods of communication today. One of the most sophisticated systems in the human body is the human visual system. Our primary sense is our visual sense, from there the importance of digital images is derived. Using different algorithms and filters, information can be gadered from digital images. This can speed up some processes or give more precise information then the information that our visual perception can see.

One area in which digital images spread to a large degree is medicine [1]. Digital images for medical purposes are obtained from various sources like ultrasound, magnetic resonance [2], radiography, tomography, nuclear medicine, etc. Different images are used for different purposes. Ultrasound images are very popular mainly because ultrasound is not invasive, it is inexpensive and it produces real time images. The internal parts of the body, such as skin, muscles, joints, vessels and internal organs can be seen using ultrasound images. In most cases the goal of diagnostics using ultrasound image is to find a source of disease or to eliminate any pathology. The following five steps describe how to obtain ultrasound image [3]:

1. System for ultrasound diagnostic (ultrasound probe which have source, receiver and display) is transmitting into the body sound pulse with high-frequency (1 to 20 MHz).

2. Sound waves travel through the body and they go to the border between tissue (for example, between fluid tissue and soft tissue or soft tissue and bone). Here reflection happens of some sound waves back to the probe, and some continue until they come to the boundary and then get reflected.

3. The probe picks up the reflected waves and sends them to the computer.

4. Using the speed of sound in the tissue (1540 m/s) machine calculates the distance from the probe to the boundary of tissue or organ and the return time of each echo.

5. At the end, the system forms a two-dimensional image by displaying the distance and intensity of the echo on the screen.

Ultrasound raw images are usually of poor quality. They can be affected by different degradations. One typical degradation is appearance of some kind of noise. Various types of noise can be presented such as amplifier noise, impulsive noise or speckle noise.

A typical representative of the amplifier noise is Gaussian noise [4]. This noise is independent on each pixel and each signal intensity. For example the blue channels can contain larger amplitude than the red and green channels, which means that the blue channels can have more noise in the color cameras.

Impulsive noise, otherwise referred to as salt-and-paper or spike noise is the most frequently occurring noise in images [5]. 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 that degrades fine details such as edges and contrast resolution [6]. One of the areas where it often appears 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 the 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 [5], transform domain filtering and wavelet based thresholding [7]. In this paper algorithm that uses spatial filtering technique is presented. This type of algorithms can be further divided into two categories, linear and non linear filtering. Linear filtering include linear filters, mean wiener filters and others, while one of the non linear filters is the median filter.

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 noise in ultrasound images. Section 4 describes the proposed algorithm for removing noise in ultrasound images. We used adjusted 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

Digital images have the influence in numerous area. Large number of application include digital images such as handwritten digit recognition [8], [9], lip detection [10], multilevel image thresholding [11], [12], microscopic imaging [13], etc. Image compression and enhancements are also popular research topics [14], [15]. Use of digital image processing in medicine enabled faster, easier and more accurate diagnosis. As mentioned before, medical digital images can be produced by different sources.

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 [16] proposed by Fontes et al. 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 [17] 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 [18] use bilateral filter added to the image infected with Gausian noise. This non-linear 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 [19]. 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.

Gupta et al. [20] propose a new multiscale geometric representation as discrete ripplet transform and non-linear bilateral filter algorithm based on them. The task of this method is to reduce the speckle noise in ultrasound images. Due to their different characteristics Ripple transformation enables effective representation of the noisy coefficients of log transformed ultrasound images. Application of the bilateral filter is based on an approximation ripple coefficients in order to improve the efficiency of denoising and effective preserve edge features.

In [21] Devarapu et al. curvelet transform was used. The curvelet transform was introduced and showed that with that representation, preservation of edges is possible. 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 [22] used multiresolutian generalized dimension N PCA method. Gaussian pyramid and multiscale image stacks on each level were 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.

Often in order to improve quality of the digital image, including improving medical digital images as ultrasound images it is necessary to use some optimization algorithms. Optimization algorithms are used for solving hard optimization problems. In recent years, swarm intelligence algorithms were very widely used and researched for solving this kind of problems. Some of swarm intelligence algorithms are bat algorithm [23], firefly algorithm [24], [25], [26], cuckoo search [27], artificial bee colony [28], [29], [30] and others.

In [31] approach based on 2D FIR filters wass presented. This approach was proposed for denoising ultrasound digital images. Idea was to filter coefficients of 2D FIR filters optimize by artificial bee colony (ABC) algorithm. In order to provide the best results, filter coefficients were tested with different numbers and connection types during the optimization. The proposed method was tested against some well known denoising techniques such as Gaussian, mean and average filters.

In [32] method for classification of breast tumors based on ultrasound images was proposed. Ultrasound breast tumors were segmented at the beginning based on a level set method. Appropriate features were extracted. Those features were used with a genetic algorithm to detect significant features and also to find the optimal parameters for the support vector machine. Support vector machine was used to identify the tumor and label it as benign or as malignant.

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, the thyroid nodule, etc. Ultrasound technique is accessible in terms of cheapness and use. It does not require the use of radiation for the purpose of treatment [33] which make this technique popular. During the biopsy and treatment, anatomical deformation can be monitored in real time using ultrasound imaging. 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. Therapeutic ultrasound is also A-mode and it is used for extremely precise focusing on the destructive waves of energy in a specific tumor or calculus.

B-mode or 2D mode (brightness mode) where linear transducer performs simultaneous scans through the body and produces a two-dimensional ultrasound images.

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.

In a plane to a B-mode, C-mode ultrasound image is created. First, data from specific dept of A-mode line is selected by gate. Then, at fixed depth transducer is moved to sample entire region in 2D plane mode.

Doppler mode [34] where visualization and measurement of blood flow is carried out by means of Doppler effect. There are four types of Doppler modes: color doppler, continuous doppler, pulsed wave doppler and duplex. In color doppler velocity of information is presented as a color-coded overlay on top of a B-mode ultrasound image. In continuous doppler mode information is sampled through the body along a line. Every sample detected at each time is presented on a time line. Pulsed wave doppler sample information from a small sample volume which is represented on the timeline. Simultaneous presentation of 2D and pulsed wave doppler information have common name duplex.

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 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 [35]. 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 is given by following equation:

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

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. Adjusted 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 [36], [37]. 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:

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

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 the third and the last step should be removing the noise which has infected ultrasound images. In our paper we use the adjusted median filter formula presented in Eq. 2 for removing the noise. At the end, the results that were obtained by removing noise are shown. The resulting image after denoising were compared with the original image that was used in the first step.

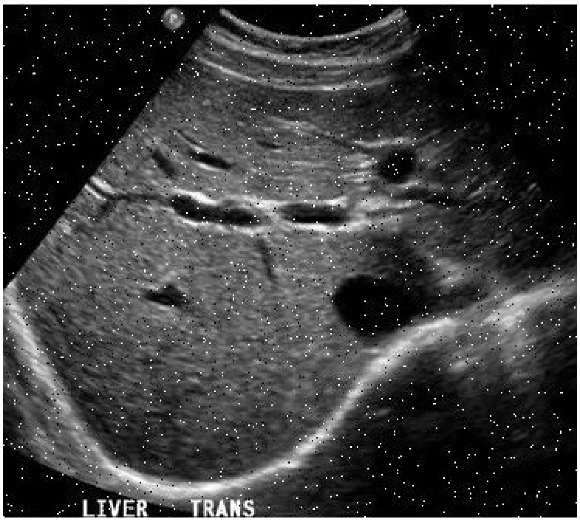
After the implementation of the chosen method for removing the noise from ultrasound image, there are some methods for testing the performance of proposed algorithm. These methods include different types of error measurements. Some of them are: MSE (Mean Square Error) PSNR (Peak Signal to Ratio), NK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

5 Experimental Results

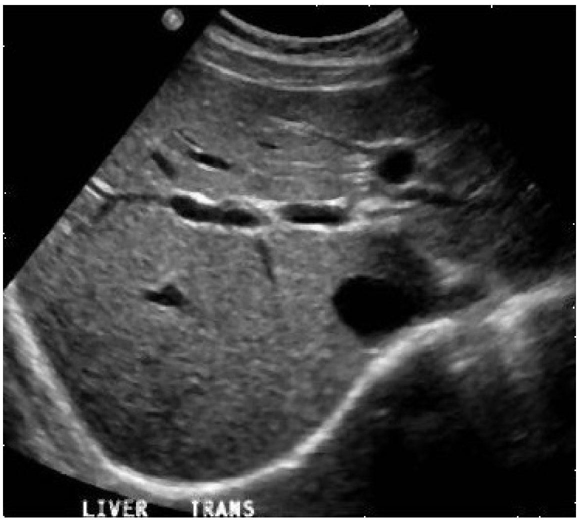
In our paper, ultrasound image denoising method experiments were performed on the computer with Intel ® Core™i5-2410M CPU at 2.30GHz, 4GB RAM, Windows 10 Home OS. Implementation of proposed algorithm were done using MATLAB (R2015a) software. Ultrasound images used in this paper are taken from the paper [38]. In Fig. 3 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. Fig. 4 presents original image, image with the noise and denoised image of ultrasound scan of the chest. As it can be seen, with our proposed method, speckle noise is almost completely removed.

Quality of the proposed algorithm can be tested by using some evolution metrics. Standard metrics used to measure quality of algorithms for denoising are used in [39]. As mentioned before, in this paper we will use MSE, PSNR, NK, AD, SC, MD, NAE and IEF. Definition of this measurements are given next.

(a) Original



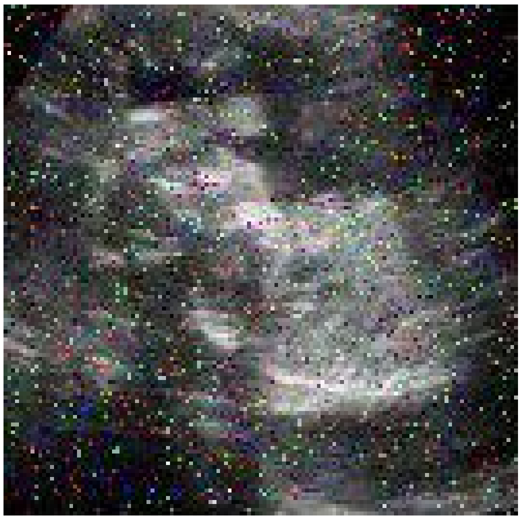
(b) Noise



(c) Denoised

Figure 1: Ultrasound images of liver

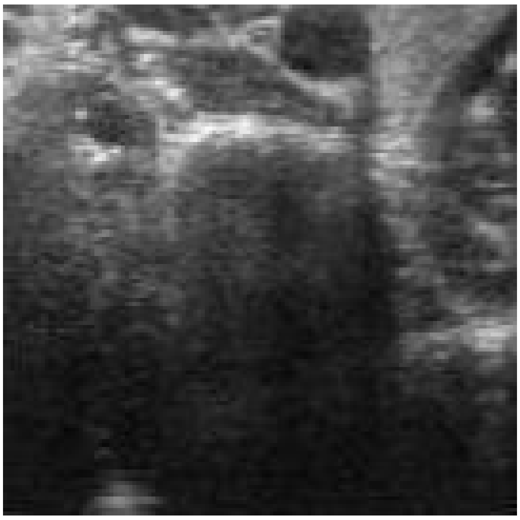
(a) Original



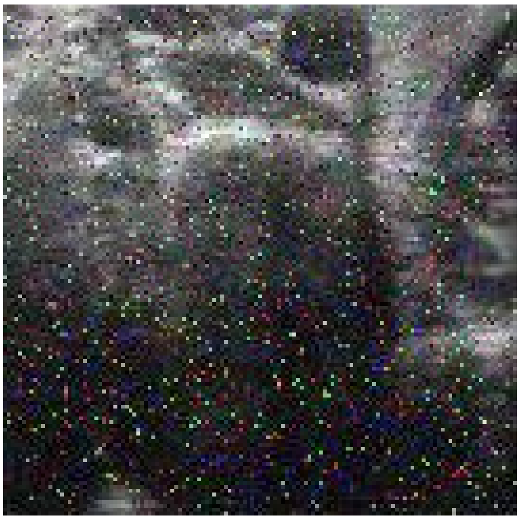
(b) Noise

(c) Denoised

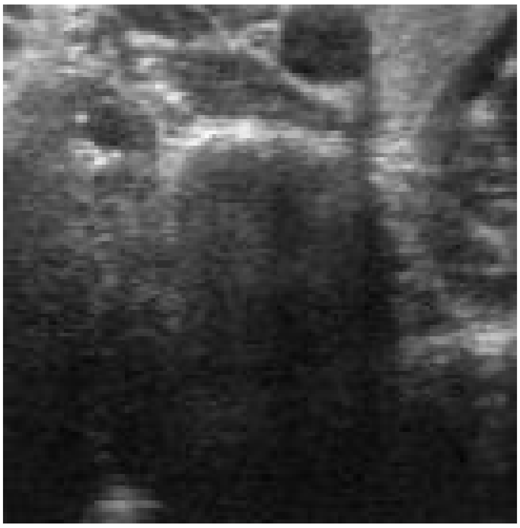
Figure 2: Ultrasound images of stomach



(a) Original



(b) Noise



(c) Denoised

Figure 3: Ultrasound images of neck

(a) Original

(b) Noise

(c) Denoised

Figure 4: Ultrasound images of chest

Table 1: Calculation of evaluation metrics

Evaluation metrics	neck		stomach		chest		liver	
	with noise	denoised	with noise	denoised	with noise	denoised	with noise	denoised
MSE	1141.3	43.4371	1160.9	136.0055	420.6907	26.1921	453.5630	54.5616
PSNR	17.5568	31.7522	17.4830	26.7952	50.4063	78.1707	49.6539	70.8320
NK	1.0170	0.9832	1.0108	0.9687	1.0915	0.9982	1.1603	0.9841
AD	3.2834	0.4655	2.9513	1.1873	2.2143	0.2314	1.7367	0.3017
SC	0.8231	1.0274	0.8443	1.0454	0.9067	0.9986	0.9182	1.0224
MD	243	101	255	110	246	217	255	254
NAE	0.0947	0.0601	0.0918	0.0866	0.0389	0.0205	0.0442	0.0349
IEF	-	1.6527	-	1.0295	-	0.9659	-	0.9702

Mean square error (MSE) is defined by the following equation:

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

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 metod used for template matching. It is a process used for finding incidences of a pattern or object within an image. This correlation is also a 2D version of Pearson product-moment correlation coefficient. Normalized cross correlationdefined 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:

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

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:

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

Calculated metrics for evaluation method used in this paper are presented in Table 1. As it can be seen images have been improved by our proposed algorithm. Mean square error should be smaller as possible. In the case of identical images, MSE would be zero. For shows that our proposed algorithm very successfully remove salt and pepper noise from ultrasound images of different organs.

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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