Scientific Research and Essays Vol. 7(26), pp. 2270-2276, 12 July, 2012
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE11.1223
ISSN 1992-2248 ©2012 Academic Journals

Full Length Research Paper

Generic computing of enhanced speckle reduction on low end ultrasound machine images

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Accepted 7 June, 2012

Due to the emergence of microelectronics, ultrasound diagnostic machine can now be manufactured at low cost. The affordability of low cost ultrasound diagnostic machine is of utter importance in allowing wider exposure of ultrasound technology to the general public. Nonetheless, in comparison with international standard requirements, the quality of images from low cost ultrasound machine is still lacking. Furthermore, the evaluation of the quality is subjective and the process is tedious. In this paper, an enhanced processing of ultrasound images using de-speckle diffusion method is proposed and the result is evaluated quantitatively on aspects such as vertical and horizontal distance accuracy, axial and lateral resolution, near field distance, penetration depth and high scatter accuracy. It comprises of the directions north, south, east and west, and the average is taken into calculation by utilizing the instantaneous coefficient of variation (ICOV) method. Algorithms are verified according to its performance in speckle reduction and edge preservation based on root mean square error (RMSE), signal-to-noise ratio (SNR) and peak signal-to-noise ratio (PSNR). The result indicates that de-speckle diffusion is more robust compared to adaptive speckle reduction method. The results obtained proved that the proposed technique could greatly improve the low cost ultrasound image quality.

Key words: Speckle, reduction, ultrasound, images, diffusion, filtering, image processing.

INTRODUCTION

Ultrasound imaging, by manipulating the characteristic of ultrasound waves as a cyclic mechanical vibration, has been implemented as one of the main medical diagnostic approaches (Shirley et al., 2010). The ultrasound machine possesses the capability of interpreting the intensity of reflected echoes resulted from the propagation of ultrasound waves in the body, based on the difference in the measurement of acoustic impedance which could give crucial information for diagnostic purposes. Major organ boundaries such as soft tissue and air can be depicted by the abrupt interface of the output, while the gradual interface represents muscle and various organs. With the intent of constructing an image for display, the reflected intensity of ultrasound waves is converted to electrical signals and subsequently transmitted through a signal processing box.

Ultrasound imaging is one of the most sophisticated medical diagnosis tools in today's medical practice due to its non-invasiveness, portability, and simplicity (Wee et al., 2010a, b). It has been widely used in obstetric ultrasound scanning and emergency medicine on account of its simplicity for user implementation and reliability in terms of safety. According to IMS Research medical research division InMedica, the users of ultrasound imaging would exceed $6 billion by 2012. Hence with this enormous number of users, the evolution of ultrasound imaging technology has begun. In early 1980s, the rapid development of computer software and microelectronics contributed in the production of smaller, portable and relatively low-cost ultrasound machines.

Currently, low cost ultrasound machines are considered as an indispensable diagnosis tool in healthcare centers.

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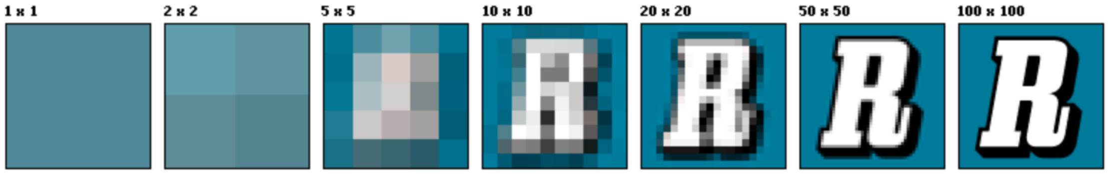


Figure 1. Clarity of image under different resolution.

Therefore, its potential in the market of medical imaging tools is tremendous, especially in developing countries such as Malaysia. Nevertheless, some performance and safety issues regarding low cost ultrasound machines have been addressed. Several unfulfilling qualities of low cost machines have failed to achieve the international standard requirement. This shortcoming would undeniably be an obstacle for further developments of low cost ultrasound machine. A low quality ultrasound machine would cause inaccuracies in medical diagnosis due to its poor image quality. Besides, it would be hazardous to a patient if the safety performance is not reliable.

Despite the advantages of ultrasound machine, it has a major drawback which is the relatively low resolution and noisy image produced compared to other advanced modalities like Magnetic resonance imaging (MRI) and CT-scan. The resolution of an image is vital in conveying message and information to viewers. Low image resolution, in other words, might imply a loss in information. Figure 1 depicts the clarity of different image resolution.

It is apparent that the degree of resolution is highly related to image quality. The higher the resolution of an image, the clearer the image will be. Generally, it is the number of pixels that affects the resolution, given that the image size is fixed. As compared to Video CD and DVD, ultrasound images have a considerably low resolution with the size of 128 x 128. To compensate for the low resolution, low cost ultrasound machines often produce diagnostic images in small sizes. The information contained in a small size image provides limited information to sonographers due to the deterioration in the details and texture of the image. Moreover, multiplicative speckle noise present in ultrasound images produced by low cost ultrasound machine could result in inaccurate diagnosis and increase the chance of missing smaller abnormalities.

The unreliability of low cost ultrasound machines is mainly caused by factors explained earlier. Only a handful of experienced sonographers have the ability to interpret low-quality diagnostic image (Ali et al., 2010; Abu Baker et al., 2007; Alsultanny, 2006; Mohammad, 2005; Mitchell and Paul, 1998; Ouadfel and Batouche, 2007; Parisa et al., 2009; Singh and Singh, 2008) and make accurate interpretations. In this paper, a generic computerized algorithm has been developed to de-speckle the low cost ultrasound images. An enhanced version of anisotropic diffusion is implemented to minimize the speckle multiplicative noise.

PREVIOUS WORKS

Theoretically, the term “image quality” can be defined as the characteristics of an image that measures image degradation as compared to the ideal image. The determination of the quality of an image is subjective, as it depends heavily on the perception of the observer. An observer might consider several aspects, for example brightness, sharpness and contrasts when observing an image, and more importantly, their interpretation about the quality of the aspects in the image quality differs from each another.

The evaluations and testing on low quality ultrasound images are of tremendous significance with the intent to assure that ultrasound machine is functional and its output is reliable. Improvements and corrective measures can be taken to ensure that the image qualities are within accepted standards.

In general, the most suitable way of assessing the image quality of an ultrasound system is by using the phantom image quality indicators (Mitchell and Paul, 1998). Ultrasound image is constructed by the strength of ultrasound echoes reflected to the probe. Due to the coherent radiation of a medium containing many sub-resolution scatterers, ultrasound image contains random speckle noise which can degrade the image quality (Yi et al., 2010). Speckle noise degrades the contrast resolution and diminishes the ability for detection with approximately a factor of eight on the image (Bamber and Daft, 1986). In order to solve this problem, many methods have been proposed including adaptive speckle reduction with color transparency display (Dong et al., 1998) and wiener filtering (Ehsan and Mohammad, 2009).

Wiener filtering in speckle reduction

Wiener filter, Jingdong et al. (2006), Scharf and Thomas (1998), Vary (1985) and Etter and Moschytz (1994) is one of the most widely adopted image de-blurring and restoration practice for poor quality ultrasound images. This filter attempts to diminish the speckle noise while restoring the original image. It carries out the optimal balance between noise reducing and inverse filtering.

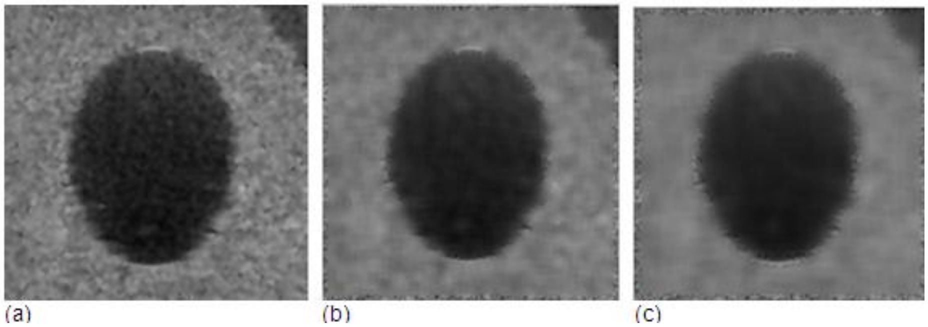


Figure 2. Speckle reducing using wiener filter, (a) neighborhood of size 5x5, (b) neighborhood of size 10x10, (c) neighborhood of size 15x15.

Wiener filter equation in frequency domain is shown in Equation 1.

$$W = \frac{g * S_{SS}}{g \cdot g * S_{SS} + S_{WW}} \quad (1)$$

Where *g* denotes the filter convolution of the input image, *Sww* denotes the power spectrum of the noise; *Sss* denotes the power spectrum of the input image.

In current studies, we have simulated a pixel wise adaptive Wiener method to filter speckle image based on statistics estimation. A suitable neighborhood of the size m-by-n is chosen to estimate the local image mean and standard deviation. Figure 2 displays the result of speckle reduction based on different neighborhood size. These simulation results are used to compare with our proposed algorithm. It can be observed that speckle noise has been smoothed when the neighborhood size becomes larger.

However, larger neighborhood size will produce a smaller noise smoothing area where there are still some speckles remained along the border of image. In short, this method produces blur and low contrast image which can degrade the ultrasound image quality. Therefore, further improvement should be performed to facilitate ultrasound screening in medical diagnosis.

MATERIALS AND METHODS

The proposed method is an edge sensitive diffusion technique for speckle in low quality ultrasound image. We have extended the diffusion method (Perona and Malik, 1990) which combined the image gradient with monotonically decreasing function, to an improved method for edge preserving. The ultrasound scanner used in this project is VGS1000-01, manufactured by Chengdu Vigorous Science and Technology Company Limited. This is one of the typical low end ultrasound machines which produce B-mode images with lower quality, in other terms, higher speckle noise. Raw image is being diffused by n-iteration to diminish the speckle noise.

Meanwhile, instantaneous coefficient of variation (ICOV) acts as edge detector to preserve the sharpness of edge during the diffusion (Acton, 1998; Yongjian and Acton, 2002). Figure 3 shows the computing algorithm design for diffusion enhancement in low quality 2D ultrasound images. Mathematically, the ICOV function can be expressed as follows.

$$q(x, y; t) = \sqrt{\frac{\left(\frac{1}{2}\right)\left(\frac{|\nabla I|}{I}\right)^2 - \left(\frac{1}{4^2}\right)\left(\frac{\nabla^2 I}{I}\right)^2}{\left[1 + \left(\frac{1}{4}\right)\left(\frac{\nabla^2 I}{I}\right)\right]^2}} \quad (2)$$

Where *I* is input image, ∇ is gradient operator, and | denotes the magnitude. The function shows higher values at edge and lower values in homogenous region. The proposed algorithm consists of north, south, east and west directional diffusion. The average of four diffusions is calculated for every iteration execution, as show in Equation 3.

$$D = \frac{((c \times dN) + (c \times dS) + (c \times dE) + (c \times dW))}{4} \quad (3)$$

Where *c* indicates diffusion coefficient and *dN*, *dS*, *dE*, *dW* represent the difference between image after diffusion and original image. The directional diffusions are shown in Equations 4 to 7.

$$dN = I_{i,j-1} - I_{i,j} \quad (4)$$

$$dS = I_{i,j+1} - I_{i,j} \quad (5)$$

$$dE = I_{i+1,j} - I_{i,j} \quad (6)$$

$$dW = I_{i-1,j} - I_{i,j} \quad (7)$$

where *i* = 1, 2, 3,…, is the width of the image, *j* = 1, 2, 3,…, is the height of the image, $I_{i,j}$ is the original ultrasound image, $I_{i,j-1}$ indicates the image shifted one pixel upward while $I_{i,j+1}$ represents the image shifted one pixel downward, $I_{i+1,j}$ shows the image shifted one pixel right and $I_{i-1,j}$ signifies the image shifted one pixel to the left hand side.

The value of the diffusion coefficient is influenced by ICOV where edge pixel area activates a lower diffusion coefficient and indirectly decreases the level of diffusion. Speckle area produces higher value of diffusion coefficient which increases the smoothing effect in certain area. Based on our findings, ultrasound image changes gradually in every execution of iteration. Larger iteration will generate a smoother image but it requires longer processing period and over-smoothing may destroy the edge of ultrasound images. Figure 4 illustrates the smoothing of ultrasound image with different

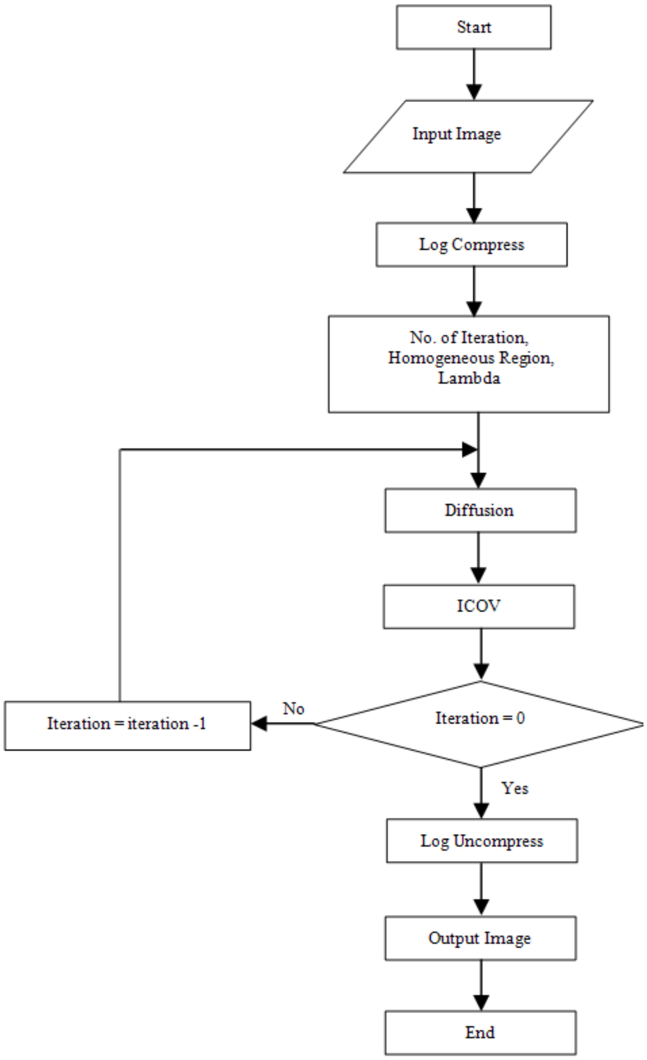


Figure 3. Process of the enhanced diffusion method.

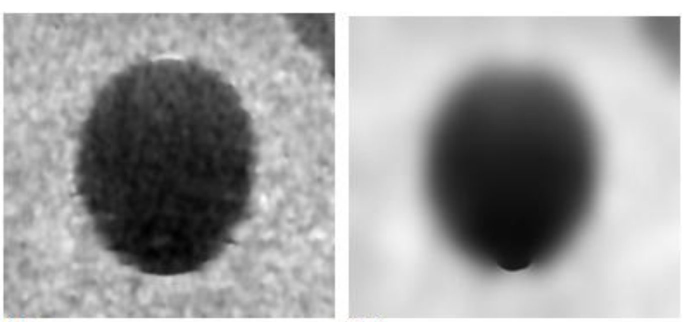


Figure 4. Level of smoothing (a) under-smoothing (b) over-smoothing.

number of iteration and smoothing time step.

Therefore, the number of iteration is adjustable due to the inconsistency of ultrasound image. Figure 5 demonstrates the image before and after enhanced using an appropriate input factor.

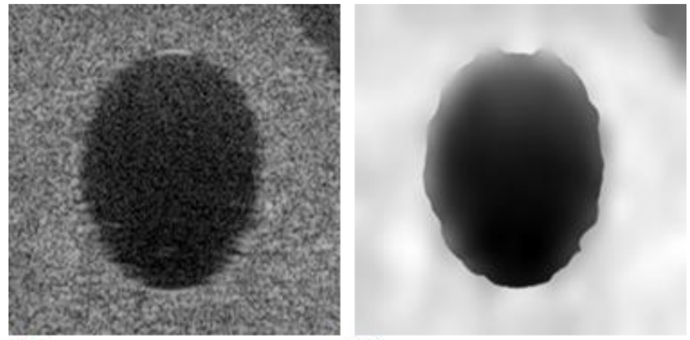


Figure 5. Image before and after enhanced.

The diffusion order can be revealed in Figure 6, which demonstrate that speckled regions are smoothed effectively and the contrast between constructive object and noise area is intensified.

RESULTS

Numerical test have been carried out to the proposed algorithm to ensure it meets the basic requirement of standard medical diagnostic. The qualitative analyzing of algorithms is verified based on its speckle reduction and edge preserving ability. Simulation results were tested on statistical measurement including root mean square error (RMSE), signal-to-noise ratio (SNR), and peak signal-to-noise ratio (PSNR). These are utilized to prove the efficiency of the proposed methods in low quality ultrasound images. RMSE calculates the average deviation from the original ultrasound image while SNR and PSNR are used to evaluate how much an image has been affected by speckle noise. A quantitative measurement of the noise level is computed by the image's standard deviation, as shown in Equation 8.

$$\sigma = \sqrt{\frac{1}{N}\sum(b_i - b)^2} \quad , i = 1, 2, 3\ldots N \qquad (8)$$

where, *N* depicts the pixel number in the image, *b* depicts the original image's mean gray level and b_i depicts the surrounding region gray level value *e*. Mathematically, the statistical measurements can be indicated in Equations 9 to 11.

$$RMSE = \sqrt{\frac{\sum(f(i,j) - F(i,j))^2}{MN}} \qquad (9)$$

$$SNR = 10\log_{10}\frac{\sigma^2}{\sigma_e^2} \qquad (10)$$

$$PSNR = 20\log_{10}\frac{255}{RMSE} \qquad (11)$$

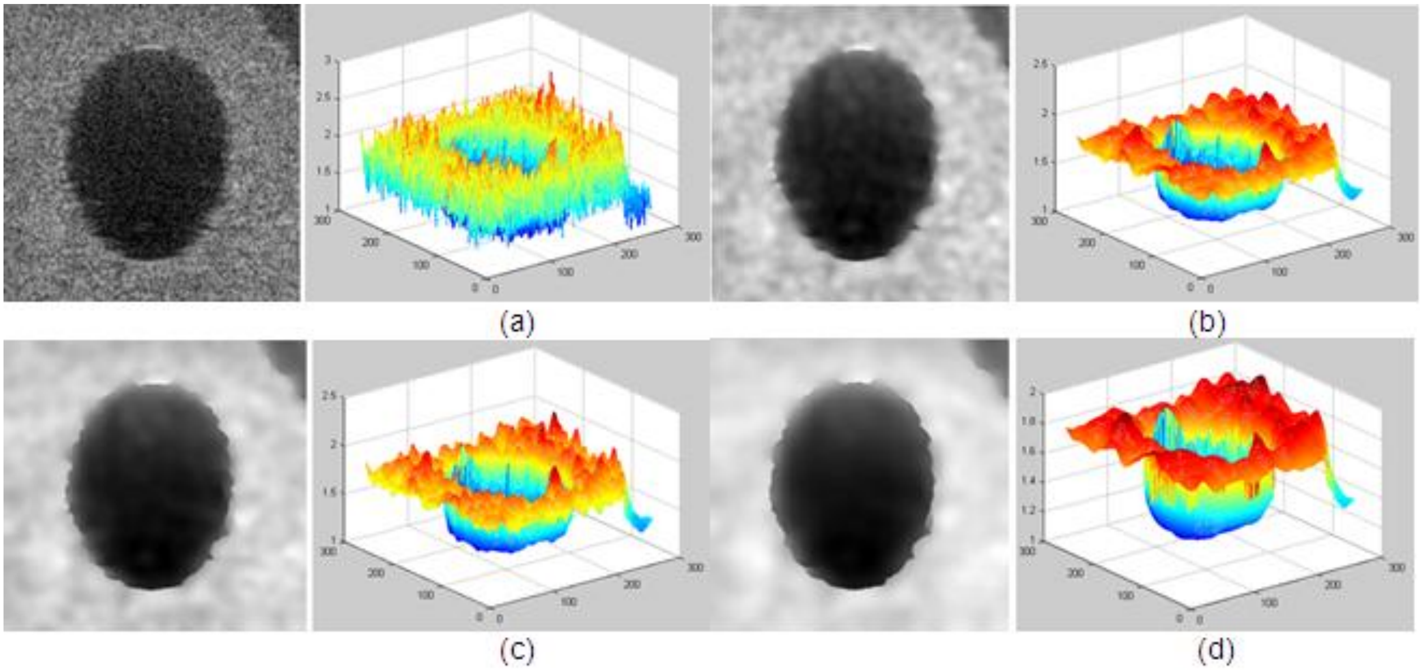


Figure 6. Diffusion based on number of iteration. (a) Diffusion iteration = 1, (b) diffusion iteration = 50, (c) diffusion iteration = 100, (d) diffusion iteration = 200.

Table 1. Statistical measurement comparison.

Variable	RMSE	SNR	PSNR
Proposed method	10.17	-2.18	27.98
Wiener filter	28.08	-12.62	19.16

Where *f (i, j)* denotes the original image and *F (i, j)* is the enhanced image. σ^2 denotes the variance of original image and σ_e^2 denotes the variance of enhanced image. To examine the robustness of the proposed method, alternative method such as Wiener filter is applied to compare the statistical measurements, as shown in Table 1.

From the findings, RMSE of the proposed method is smaller and the values SNR and PSNR are larger than Wiener filter. Larger RMSE represents a vast deviation from the original image, where it can diminish the integrity as well as damaging the important information in ultrasound image. Meanwhile, PSNR and SNR reveal the highest value in the proposed method. This results shows that the enhancement of proposed method are more effective in speckle noise reduction on ultrasound image. Figure 7 shows the difference between the proposed method and Wiener noise reduction method.

Besides, quantitative analysis was also carried out to track the consistency of the algorithm's performance. A total of 20 sample images of the cyst from ultrasound phantom were captured and its diameters were measured before and after the execution of proposed algorithms. A line chart is plotted according to the simulated results. The standard values for the diameter of the cyst are plotted as a reference line in Figure 8.

It can be observed that the values of cyst diameters for enhanced image are closer to the standard measurement, which is 5 mm in ultrasound phantom Gammex. However, values of cyst diameter for raw images are diverged further from the standard value. This indicates that the proposed method produces improved ultrasound images. Figure 9 shows part of the simulation results applied on ultrasound phantom Gammex. The results illustrate that speckle noise from the original ultrasound images has been diminished and smoothened while still retaining the edges in the images.

DISCUSSION

Despite the satisfying result of using the proposed method, it has certain limitations such as the deterioration of information and originality of an object's shape and

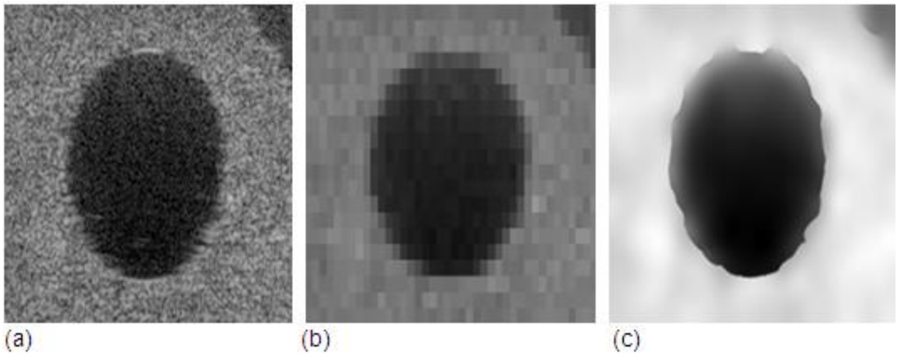


Figure 7. Results comparison (a) Original image, (b) image after Wiener noise reduction, (c) image after proposed enhancement techniques.

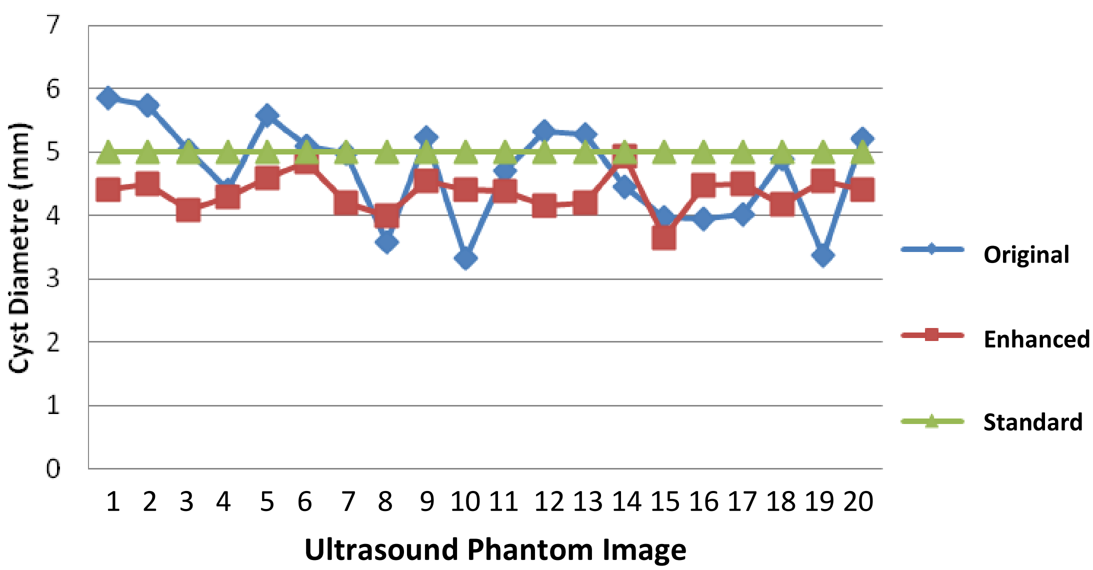
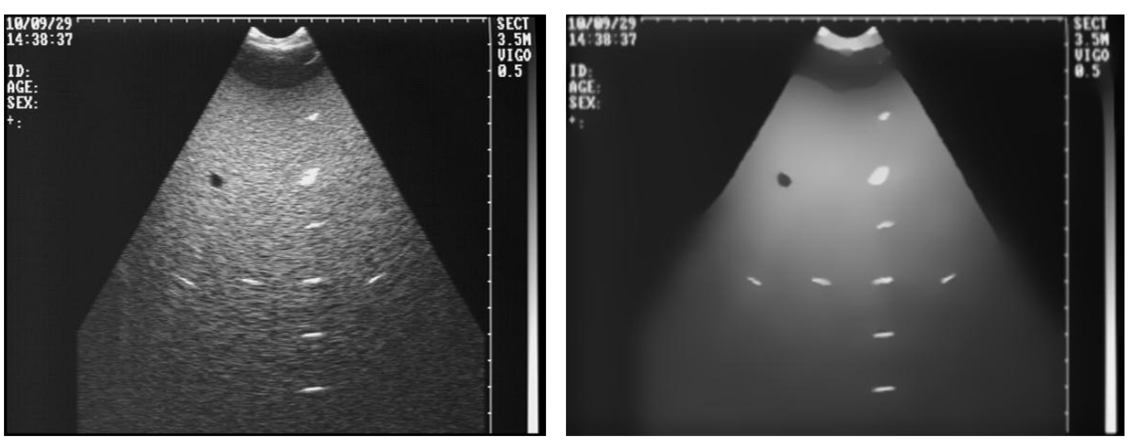


Figure 8. Cyst diameter measurements.



(a) (b)

Figure 9. Simulation result on ultrasound phantom (a) raw image (b) after proposed diffusion.

size in ultrasound image. These limitations are more frequent in images from low end ultrasound machine. Therefore, external signal processing and hardware improvement such as synthetic aperture techniques should be adopted in order to enhance the raw imaging quality. Echo signal from ultrasound wave is the fundamental element for the formation of ultrasound images. The speckle noise should be recognized during the signal propagation so that suitable or designated filters can be applied to eliminate the speckle noise.

Besides, real time clinical testing on a variety of ultrasound scanning has to be done to generate different improvement method. This is extremely beneficial since the proposed method could not be fitted perfectly to all kind of screening. Consequently, a small alteration should be made to increase the adaptability of the proposed method.

Conclusion

An integration of the proposed speckle reduction has been developed in order to improve the low cost ultrasound image quality. It is tested by using images of the ultrasound phantom, and had shown promising results. Thus it is proven to be effective in improving the image quality. The integrated algorithm is able to reduce speckle noise in images consistently and hence make the image clearer and more accurate for diagnosis purpose.

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