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Enhancement of ultrasound images using stochastic resonance-based wavelet transform

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Abstract

Ultrasound diagnostic imaging technique is used to visualize muscles and internal organs, their size, structures and possible pathologies or lesions. The limited soft tissue contrast of ultrasound may lead to problems in characterizing perivascular soft tissues. We develop a technique using stochastic resonance (SR)-based wavelet transform for the enhancement of unclear diagnostic ultrasound images. The proposed method enhances the edges more clearly. The advantages of this method are that it can simultaneously operate both as an enhancement process as well as a noise-reduction operation, and that the method can also optimally enhance an image even if the image noise level is considerable.

Keywords: Stochastic resonance; Wavelet transform; Image enhancement; Noise; Ultrasound imaging

1. Introduction

Ultrasound is widely available, portable and noninvasive. It is an important aid in the diagnosis of especially carotid, brachial, femoral as well as other peripheral arteries. Most importantly, it allows real-time visualization of arterial lumen and wall that is not possible with any other imaging modality. Although X-ray contrast angiography offers real-time imaging, the image information is limited to the vessel lumen and no information about the vessel wall is available. Also the insufficient spatial image resolution, the need for injection of blood pool contrast agents, as well as low volumetric imaging speed are limiting the utility of CT and MRI to lumen visualization of large vessels. However, ultrasound cannot able to image certain vascular structures because they offer no acoustic window or are obscured by bowel gas. The limited soft tissue contrast of ultrasound may lead to problems in characterizing perivascular soft tissues. So ultrasound images needs better contrast enhancement techniques to lessen the noise.

Noise is not always deleterious to a system. Optimal amount of noise enhances the degree of order in a system. Stochastic resonance is one of the most significant and relatively simple examples of this type of nontrivial behavior of dynamic systems under the influence of noise. The notion of SR determines a group of phenomena wherein the response of the system to a weak input signal can be significantly increased with appropriate tuning of the noise intensity [1,4,5]. Because of the noticeable advantage in enhancing weak signals, SR seems to have implications for medical imaging as it plays a growing role in many diverse fields.

Hongler et al. [2] found that the ubiquitous presence of random perturbations in visual systems can favorably be used for edge detection. Marks et al. [3] studied that SR of a threshold detector in image visualization, wherein an optimal noise level produces a better visual representation than when other levels of noise is used. Threshold detectors for signals or images play an important role in adaptive stochastic resonance systems [6].

Various noise reduction techniques have been proposed for ultrasound images such as noise reduction using thresholding [7–10], noise suppression or denoising using wavelets [11–18]. These approaches have a problem that one has to tune in advance the *ab initio* or arbitrary scale-specific or scale-dependent parameters. To avoid this problem we propose an approach using stochastic resonance. One of the newer techniques for signal enhancement is by using the SR phenomena, hence we are motivated here to explore whether the same can be applied to radiological images. If so, this would give a new paradigm, which would enable optimal enhancement of a radiological image. The advantage of the proposed SR technique over conventional image processing techniques is

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that in the latter, we need to denoise the image using filters and then enhance the image, whereas the former is a more direct approach that does not need any filter to remove the noise, instead noise is used to counter noise. In other words, small amount of extra noise is administered to ameliorate the intrinsic noise already in the image. This SR technique works more efficiently for medical (radiological) images as these images contains inherent noise. In this paper, we explain the procedure to utilize SR to enhance the ultrasonic images.

2. Materials and methods

Ultrasound images of about 30 patients of different cases were obtained in Dicom file format. The study was cleared by the Institutional Human Ethics Committee. Two well qualified and experienced radiologists evaluated the images with consensus. We applied this method to ultrasound images of breast, abdomen, vascular arteries and veins. We selected the slice which had the maximum cross-sectional area of the lesion for processing. Such sliced images were subjected to SR-based wavelet transform by selecting the region of interest (ROI). In the following subsection we discuss the proposed SR model and the methodology of SR-based wavelet transform.

2.1. Bistable stochastic resonance (SR) model

Investigators have studied the stochastic resonance of a threshold detector in image visualization, wherein an optimal noise level produces a better visual representation than when other noise levels are used. The stochastic resonance effect requires three basic ingredients: (1) a form of threshold, (2) a source of noise and (3) a weak input source. Bistable stochastic resonance systems have been used to enhance the weak noisy signals of 1D, and here we use SR to enhance an 2D signals or images. We propose a bistable SR system operating in the wavelet domain.

We now elucidate the bistable SR model in theoretical form that is conventionally used by physicists. We are interested to ask how an image pixel would transform if noise ε is added, so that the pixel is transferred from a weak-signal state to a strong-signal state, i.e. a binary-state transition occurs. Such an image pixel under noise can be modeled by particle under thermodynamic noise (Brownian motion) that transits between two states.

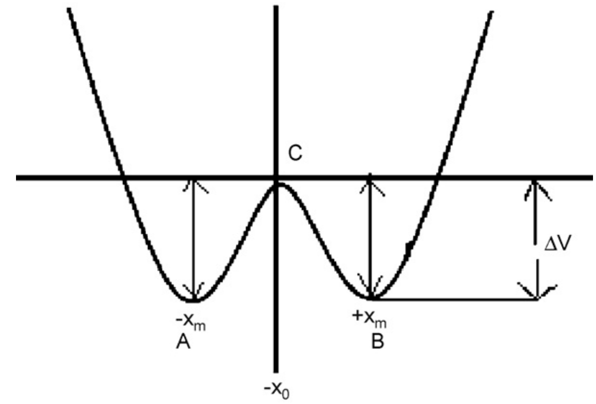

Fig. 1. Bistable quartic double well stochastic resonance model.

The latter model is well known in classical physics, namely the transition of a Brownian particle between two states, having a bistable potential, $V(x)$ given by $V(x) = (-a/2)x^2 + (b/4)x^4$ where x is the particle [1]. The particle rides on a weak signal that can be represented most simply as a zero-mean signal such as sinusoid.

The aim is to see whether a small amount of noise added to the particle in A (Fig. 1) will cause it to move from weak-signal state to strong-signal state, transiting over the visualization threshold C that has a threshold potential, ΔV. The potential minima A and B are located at $x_{\mathrm{m}} = \pm\sqrt{a/b}$, while the height of the threshold potential barrier between the two states is $\Delta V = (a^2/4b)$ (Fig. 1). The entire computational procedure of image enhancement using proposed method is shown below in Fig. 2.

2.2. SR-based wavelet transform

The wavelet transform can be thought of as the cross-correlation of an image with a set of wavelets of various scales. The wavelet transform of a continuous signal, S is defined as

$$W(x, k) = \int_{-\infty}^{\infty} \psi\left(\frac{x - x'}{k}\right) S(x')\mathrm{d}x' \qquad (1)$$

w.r.t. wavelet function ψ and 'k' is the only adjustable parameter for the filter. The wavelet size is measured in pixels, the least unit of an image. The filter transforms the original spatial distribution

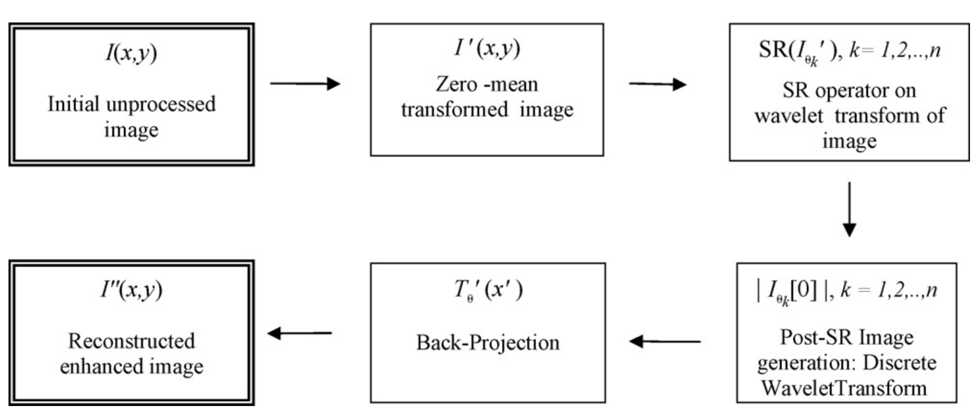

Fig. 2. Computational procedure for the enhancement using stochastic resonance-based wavelet transform.

of intensities into a spatial distribution of correlations that has the visual appearance of original image but with strong high lighting of the regions whose size is similar to the wavelet size. The maximum response of the correlation is obtained when the characteristic size of the feature of interest equals to wavelet size 'k'.

Let $I(x, y)$ be an image, its wavelet transform is defined as follows:

$$W(x, y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(x, y)W(x, y, k)\mathrm{d}x\mathrm{d}y \tag{2}$$

To enable SR to occur, we need to transform the image $I(x, y)$ into a new image $I'(x, y)$ to a zero-mean signal such that

$$I'(x, y) = I(x, y) - \langle I(x, y)\rangle \tag{3}$$

where $\langle I(x, y)\rangle$ is the spatial average value of pixel intensity of the original image $I(x, y)$.

Now we add the stochastic resonator SR to the transformed image $I'(x, y)$, thus obtaining the SR-based wavelet transform:

$$W(x, y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mathrm{SR}\;\; I'(x, y)W(x, k)W(y, k)\mathrm{d}x\mathrm{d}y \tag{4}$$

where stochastic resonator SR can be given as

$$\dot{x}(t) = -V'(x) + A_0\cos(\Omega t + \phi) + \xi(t) \tag{5}$$

To get a better signal, we make the cosine term to unity and substituting $V'(x)$ in Eq. (5) we get:

$$\dot{x}(t) = ax(t) - bx^3(t) + A_0 + \xi(t) \tag{6}$$

3. Results

In this section, we presented the results obtained using the proposed approach. We collected the image sequences of the patients in Dicom format. We have selected a best slice from the image sequence which gives maximum cross-sectional area of the lesion and crop the region of interest for image enhancement.

In medical diagnosis with reference to image contrast enhancement, it is better to really deal with a combined system of the display device (using image processing techniques) and the human visual system. Surprisingly, most of the existing methods for contrast enhancement focus on the properties of the image to be processed without consideration of the characteristics of the human visual system. From the point of view of optimal information transfer, the computerized enhancement process such as proposed methodology is used to display an image that tends to match the characteristics of the human visual system. The development of a high performance contrast enhancement algorithm must hence attempt to enhance the local contrast of the image based not only on the local characteristics of the image but also on some basic human visual properties, especially those properties related to contrast.

The best-enhanced image was chosen from a matrix of 25 images with different values of A (0.006:0.001:0.01) and B (0.06:0.01:0.1). We selected the enhanced image based on the contrast noise ratio (CNR) of the image and the basic human visual properties, i.e. observer's just-noticeable-mapping difference (JND). The proposed algorithm always produces adequate contrast in the processed (output) image, and results in almost no ringing artifacts even around sharp transition regions, which is often seen in images processed by the conventional contrast enhancement techniques. Also we have verified the best-enhanced image selection through visual inspection by expert radiologists and there was excellent agreement for almost all the images. The image histograms are displayed to the right of the respective images.

(i) A poor quality of ultrasound scan image of abdomen is shown in Fig. 3(a) and we apply SR technique on the original image. The image gets enhanced and the lesions are clearly visible using the proposed SR-based wavelet transform as shown in Fig. 3(b).
(ii) Fig. 4(a) shows a ultrasound image which fails to show the stones in gall bladder. The enhanced image using SR-based wavelet transform shown in Fig. 4(b) clearly shows the stones in the gall bladder for the parameter values $a = 0.007$ and $b = 0.09$.
(iii) Fig. 5(a) shows a poor quality of transverse internal jugular vein and carotid artery image with lesion in which surrounding edema faintly visible, which is easily evident in enhanced image shown in Fig. 5(b) for $a = 0.006$ and $b = 0.06$.
(iv) The proposed method was able to enhance structural lesions of an ultrasound mammogram also made hazy lesions prominent. Fig. 6(a) shows an ultrasound image of a breast in which the lesions are unclear. The enhanced image stand out the hazy lesions in the breast as shown in Fig. 6(b) for $a = 0.008$ and $b = 0.07$.
(v) Fig. 7(a) shows the blurred image of a carotid artery. The proposed method was able to enhance the carotid artery

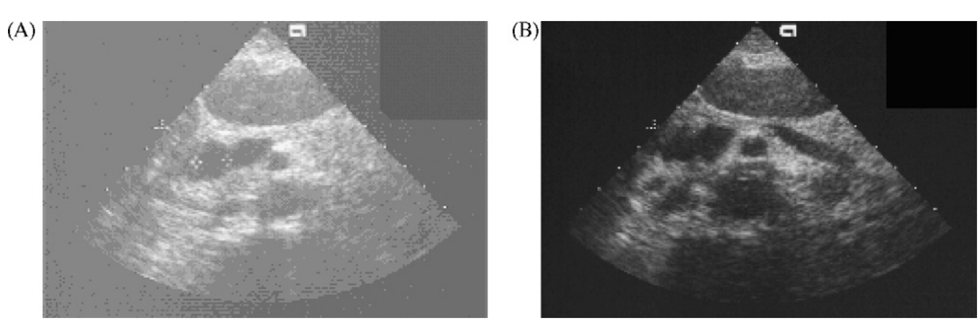

Fig. 3. (A) Original ultrasound image. (B) Enhanced image using SR-based wavelet transform.

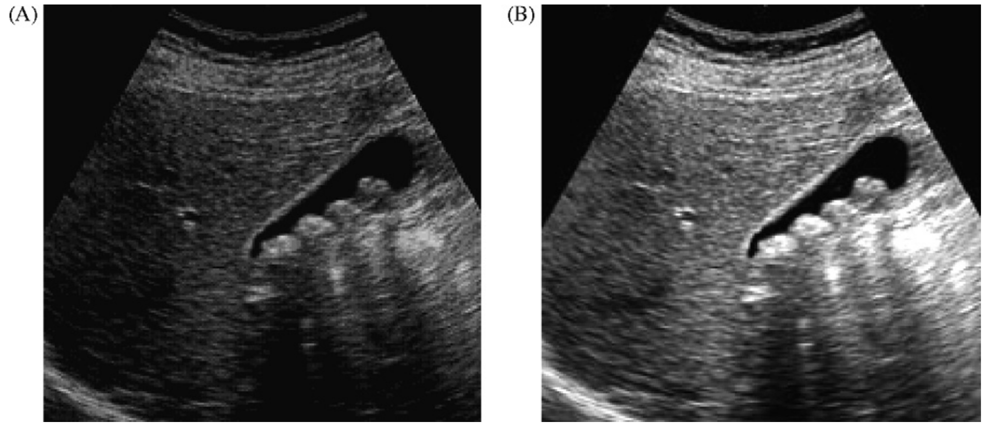

Fig. 4. (A) Original image. (B) Enhanced image using SR-based wavelet transform.

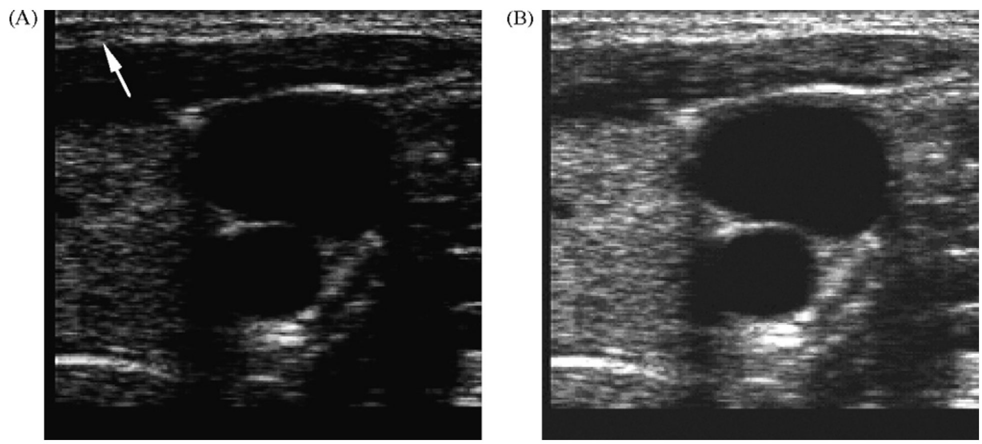

Fig. 5. (A) Original image of jugular vein and carotid artery. (B) SR-based enhanced image.

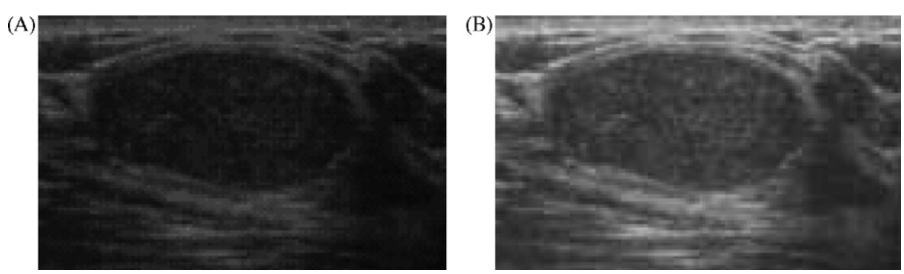

Fig. 6. (A) Original ultrasound breast image (B) Enhanced image using SR wavelet transform.

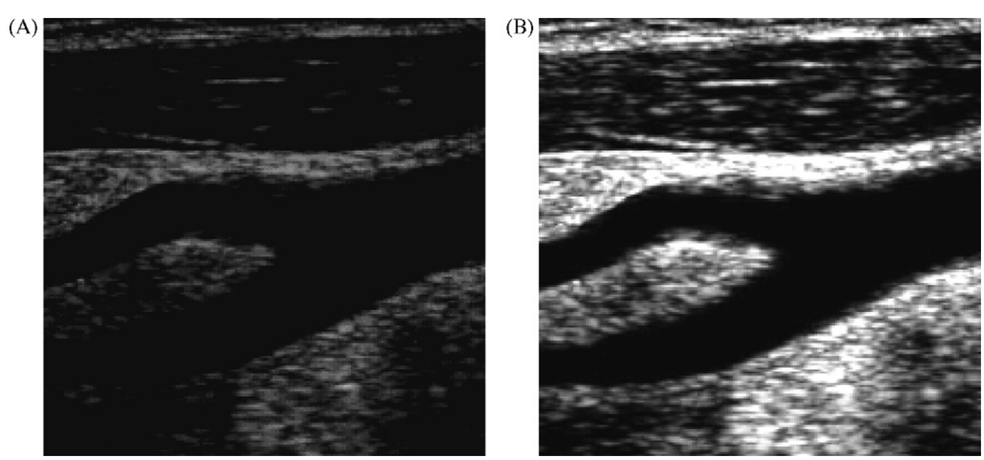

Fig. 7. (A) Original ultrasound image of carotid artery (B) Enhanced image using SR wavelet transform.

bifurcation and delineate its margins as seen in Fig. 7(b) for $a = 0.008$ and $b = 0.06$.

4. Discussion

In this section, we discuss the clinical implications of the proposed technique. Commercially available imaging softwares cannot enhance the perivascular soft tissue images. But the proposed technique is based on enhancement of a poor visioned or unclear image and it helps for routine clinical use because it is very less time consuming. Hence, it provides further subjective improvement in the image appearance, and may provide additional benefits in diagnostic accuracy. Also it aid clinicians to extract the hidden or vauge information in the ultrasound images without introducing unwanted artifacts. Our method improves contrast and edge detection. We applied this method to ultrasound images of breast, abdomen, vascular arteries and veins and got successful results and some of the results has been shown in this paper. Our method can be too widely applicable for other medical image modalities and general image processing problems.

References

[1] Gammaitoni L, Hanggi P, Jung P, et al. Stochastic resonance. Rev Mod Phys 1998;70(1):223–87.
[2] Hongler M, Meneses Y, Beyeler A, et al. The resonant retina: exploiting vibration noise to optically detect edges in an image. IEEE Trans Pattern Anal Mach Intell 2003;25(9):1051–62.
[3] Marks RJ, Thompson B, El-Sharkawi MA, et al. Stochastic resonance of a threshold detector: image visualization and explanation. In: Proceedings of the IEEE international symposium on systems and circuits. 2002. p. 521–3.
[4] Ye Q, Huang H, He X, et al. A study on the parameters of bistable stochastic resonance systems and adaptive stochastic resonance. In: Proceedings of the IEEE international conference on robotics, intelligent systems and signal processing. 2003. p. 484–8.
[5] Anischenko VS, Neiman AB, Moss F, et al. Stochastic resonance: noise-enhanced order. Physics-Uspekhi 1999;42(1):7–36.
[6] Mitaim S, Kosko B. Adaptive stochastic resonance. Proc IEEE 1998;86(11):2152–83.
[7] Lazaro JC, San Emeterio JL, Ramos A, Fernandez JL. Influence of thresholding procedures in ultrasonic grain noise reduction using wavelets. Ultrasonics 2002;40:263–7.
[8] Johnstone IM, Silverman BW. Wavelet threshold estimators for data with correlated noise. J Roy Stat Soc 1997;59:319–51.
[9] Donoho DL. De-noising by soft thresholding. IEEE Trans Inform Theory 1995;41:613–27.
[10] Jansen M. Noise Reduction by Wavelet Thresholding. Lecture notes in Statistics, vol. 161. Springer-Verlag; 2001. p. XXI 191.
[11] Abbate A, Koay J, Frankel J, Schroeder SC, Das P. Signal detection and noise suppression using a wavelet transform signal processor: application to ultrasonic flaw detection. IEEE Trans Ultrason Ferroelectr Freq Control 1997;44:14–25.
[12] Coifman RR, Donoho DL. Translation-invariant de-noising. Wavelets and Statistics, Lecture Notes in Statistics, vol. 103. Springer-Verlag; 1995. pp. 125–150.
[13] Nason GP, Silverman BW. The stationary wavelet transform and some statistical applications. Wavelets and Statistics, Lecture Notes in Statistics, 103. Springer-Verlag; 1995, 281–299.
[14] Lang M, Guo H, Odegard JE, Burrus CS. Noise reduction using an undecimated discrete wavelet transform. IEEE Signal Process Lett 1996;3:10–2.
[15] Shensa MJ. The discrete wavelet transform: wedding the a'trous and Mallat algorithms. IEEE Trans Inform Theory 1992;40:2464–82.
[16] Donoho DL, Johnstone IM. Ideal spatial adaptation by wavelet shrinkage. Biometrika 1994;81:425–55.
[17] Donoho DL, Johnstone IM. Adapting to unknown smoothness via wavelet shrinkage. J Am Stat Assoc 1995;90:1200–24.
[18] Pardo E, San Emeterio JL, Rodriguez MA, Ramos A. Noise reduction in ultrasonic NDT using undecimated wavelet transforms. Ultrasonics 2006;44:e1063–7.

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