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# Improvement of Speckle Noise Reduction Using Multi-resolutional Coherence Measurement in Ultrasound Image

Ju Won Kwon and Yong Man Ro, *Senior Member, IEEE*

*Abstract*—**Ultrasound (US) images are degraded by speckle noise that reduces the contrast and details of images. But the effective method for speckle noise reduction with keeping edge has been still a challenging point. Coherence measurement has been used to distinguish homogeneous region and coherence regions, e.g. edges, and the edge map obtained from coherence measurement has limitation such as noisy or discontinued edge detection. In this paper, to overcome these problems, the enhanced edge map generation using multi-resolutional coherence measurement is proposed and adaptive wavelet based-speckle noise reduction is performed using the enhanced edge map. The experimental results showed that the enhanced edge map by proposed method contains the robust and linked edge information. Moreover, the results show that the proposed method outperforms the conventional method in preserving edge details.**

## I. Introduction

Speckle noise is a phenomenon produced by interfering echoes of a waveform that is emitted from heterogeneous attributes of the studied objects, which shows multiplicative property and its scale is from zero to maximum value depending on whether the interference is destructive or constructive [1]-[2]. Speckle noise causes degradation of the quality and reliability of medical ultrasound image, because it tends to reduce the image contrast and image details.

Thus, many methods for speckle noise reduction have been studied. A speckle-reducing anisotropic diffusion (SRAD) that is a nonlinear diffusion filter approach to spatial adaptive filtering shows effective results of speckle noise reduction in homogeneous region with edge preservation [3]. However, it does not show enough results of speckle noise reduction in low contrast edges and bright regions. Another approach to anisotropic diffusion filter for speckle reduction is Gaussian smoothing method based on nonlinear coherence diffusion (NCD) model [4]. It is useful for finding edge and its orientation; however, it is difficult to find various sized edges due to its single-scale approach. In multi-scale techniques, wavelet-based speckle noise reduction methods have been studied [5]. It is useful to reduce speckle noise using spatial and frequency information of the decomposed image into multi-scales. Moreover, the wavelet Bayes shrinkage that uses the threshold value depending on the statistics of each wavelet sub-band based on Bayesian estimator shows the outperformed noise reducing ability. But, because the edge and speckle noise within the same wavelet sub-band are removed with the same threshold value, the loss of edge details is inevitable.

To overcome these problems, coherence measurement that discriminates homogeneous, and coherence, e.g. edge, regions is used to avoid smoothing edges. Coherence measurement has been known as the effective tool to obtain edge information in images [6]-[7]. Edge map is obtained by thresholding a coherence map. However, due to the trade-off between noisy and detailed edge detection, the edge map generated by the simple threshold has limitation to determine the optimal threshold. Low threshold value results in noisy edge map, whereas high threshold value cannot detect edge information, thereby some edges could not be detected, and edges are disconnected.

In this paper, the enhanced edge map using hierarchical coherence map by multi-resolutional coherence measurement is proposed that overcomes the above problems, and adaptive wavelet Bayes shrinkage is performed by applying the enhanced edge map, which preserves edges and details of the image while smoothing speckle noise. To verify the validity and suitability of the proposed method, liver ultrasound image is used in the experiment.

This paper is organized as follows. Section 2 explains the overall procedure of edge preserving wavelet-based speckle noise reduction using Bayes shrinkage and coherence measurement that was performed in our previous work. In section 3, the proposed enhanced edge map generation by multi-resolutional coherence measurement is explained. Section 4 shows the effectiveness of the proposed edge map and the performance of the proposed noise reduction comparing with the conventional method. Finally, we conclude this paper in section 5.

## II. Edge Preserving Wavelet-Based Speckle Noise Reduction using Coherence Measurement

A generalized model of the image containing speckle noise is as

$$g(i,j) = f(i,j)u(i,j) + \xi(i,j), \tag{1}$$

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J. W. Kwon and Y. M. Ro are with the Image and Video System Laboratory, Korea Advanced Institute of Science and Technology (KAIST), Daejeon 305-732, South Korea (e-mail: jw.kwon@kaist.ac.kr; ymro@ee.kaist.ac.kr)

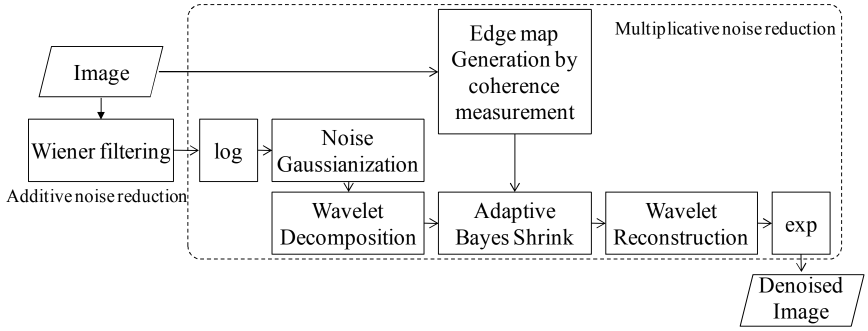



Fig. 1. The procedure of edge preserving wavelet-based speckle noise reduction

where $g$ and $f$ are observed and original images, respectively. $u$ is multiplicative speckle noise and $\xi$ is additive Gaussian noise [8]. Thus, the reduction method for speckle noise should consider both additive and multiplicative components in speckle noise.

The procedure of edge preserving wavelet-based speckle noise reduction is shown in Fig. 1. To remove additive component of speckle noise, it adopts Wiener filter. And logarithmic transformation is applied to the image in order to convert multiplicative speckle property to additive one. After that, noise gaussianization is performed as preprocessing to prevent the efficiency decrease of noise reduction caused by statistics of logarithmically transformed speckle noise which is the Fisher-Tippett distribution, not the Gaussian one, because lots of noise reduction methods including Bayes shrinkage that is used in this paper are based on the Gaussian noise distribution [1]. In the noise gaussianization step, the outliers of Fisher-Tippett noise are removed by subtracting its spiky component. Then, the wavelet-based noise reduction is performed to reduce the gaussianized speckle noise, which adopts Bayes Shrink scheme for thresholding in wavelet domain and the edge map obtained from coherence measurement for edge preserving. By selectively applying wavelet Bayes Shrinkage in each sub-band using the edge map as shown in Eq. (2), the speckle noise could reduce effectively with keeping edge.

$$R=\begin{cases}\operatorname{sign}(c) & \text{if } E(i,j)=1\\ \operatorname{sign}(c)\max\left(0,|c|-\dfrac{\sigma_{u_l}^2}{\sqrt{\max(\sigma_{sb}^2-\sigma_{u_l}^2,\,0)}}\right) & \text{otherwise}\end{cases}, \tag{2}$$

where, $R$ indicates the results of the thresholded wavelet coefficients, and $c$ represents wavelet detail coefficients. $\sigma_{u_l}^2$ and $\sigma_{sb}^2$ are variance values of log transformed speckle noise and coefficients of the sub-band, respectively. $E(i,j)$ represent the edge map and has the value of 1, if the pixel belongs to edge area. Finally, the denoised image is obtained from inverse wavelet transform of the thresholded wavelet coefficients and exponential transformation.

## III. Proposed Edge Map Enhancement by Multi-Resolutional Coherence Measurement

### A. Edge map generation by coherence measurement

Edge map in Fig. 1 is generated from coherence measurement. Coherence measurement is used to distinguish homogeneous region and coherence regions such as edges, which is adopted in the anisotropic diffusion model [4],[7]. Coherence measurement is based on the structure tensor referred to as the second-moment matrices. The structure tensor of a coordinate in image $I(x,y)$ is given by,

$$\begin{aligned}\mathrm{J}_\rho(\nabla \mathrm{I}) &= K_\rho * \left(\nabla \mathrm{I}\cdot\nabla \mathrm{I}^{\mathrm{T}}\right)\\ &= \begin{pmatrix} K_\rho * I_x^2 & K_\rho * I_x I_y\\ K_\rho * I_x I_y & K_\rho * I_y^2\end{pmatrix},\end{aligned} \tag{3}$$

where $\nabla$ I is image gradient and $I_x$ and $I_y$ are partial derivatives of image the $I$ along x- and y- axis. $K_\rho$ and * denotes Gaussian weighting function with variance $\rho$ and convoultion operation, respectively. The eigen-analysis of the structure tensor is described by Eq. (4), which gives information of the local image characteristics:

$$\mathrm{J}_\rho(\mathrm{I}) = (\boldsymbol{\omega}_1 \quad \boldsymbol{\omega}_2)\begin{pmatrix}\mu_1 & 0\\ 0 & \mu_2\end{pmatrix}\begin{pmatrix}\boldsymbol{\omega}_1^{\mathrm{T}}\\ \boldsymbol{\omega}_2^{\mathrm{T}}\end{pmatrix}. \tag{4}$$

The eigenvectors $\boldsymbol{\omega}_1$ and $\boldsymbol{\omega}_2$ show the direction of maximum and minimum variations, respectively. And $\mu_1$ and $\mu_2$ are eigenvalues of eigenvectors $\boldsymbol{\omega}_1$ and $\boldsymbol{\omega}_2$ correspondingly. The eigenvectors $\boldsymbol{\omega}_1$ represents the direction where the intensity is changed abruptly, that is called as edge direction, and the eigenvectors $\boldsymbol{\omega}_2$ is tangential direction to the edge direction called as coherence direction. Thus, the coherence value, the difference value between eigenvalues corresponding to two directions, can represent the degree of coherence [7],[9]. In other words, the region with anisotropic nature such as edges has a large difference between two eigenvalues, whereas homogeneous region.

In the previous works, the edge map by coherence measurement that demonstrates the edge position in an image is used for adaptive Bayes shrinkage, which cloud be obtained as following,

$$E(i,j)=\begin{cases}1 & \left\| \mu_1 \right| - \left| \mu_2 \right\| > \lambda_c \\ 0 & \text{elsewhere}\end{cases}. \quad (5)$$

If the coherence value, the degree of coherence, is larger than the predefined threshold value $\lambda_c$, the region includes edges, while if it is smaller than $\lambda_c$, the region is considered as speckle noise.

### *B. Enhanced Edge Map by Multi-resolutional Coherence Measurement*

In order to perform selective wavelet based speckle Bayes shrinkage using the edge map, it is important to obtain the correct edge information. However, the edge map generated by thresholding coherence map has limitation due to the trade-off between noisy and detailed edge detection. It is difficult to determine the optimal threshold that distinguishes noisy and detailed correct edges. In other words, if a low value is used for thresholding, the generated edge map has lots of noise, while if a high value for thresholding is adopted, the edge map has disconnected or undetected edges, which are shown in Fig. 2.

As seen in Fig. 2, when the edge map is generated by the low threshold value, it includes not only the edge but also lots of noise; whereas the edge map generated by the high threshold value does not contain enough edge information thereby edge is disconnected or not detected. To remove the noise in the edge map as shown in Fig. 2 (b), the linear filter, e.g. Gaussian low pass filter, has been used [9]. It reduces some noise in the edge map; however, it also causes smoothing of the edge details. Thus, it is hard to get fine edge information with this approach.

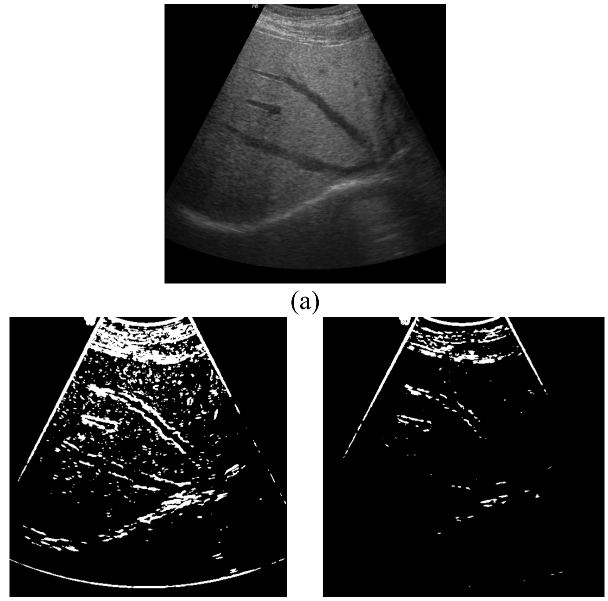



Fig. 2. The liver image with blood vessels and the generated edge maps depending on the threshold value: (a) original image, (b) the result by the low threshold value, (c) the result by the high threshold value

To attain robust and linked edge information, the proposed method adopts the hierarchical coherence map that is obtained from measured coherence value from multi-resolutional images. Figure 3 describes the procedure of the proposed edge map generation. It could also be explained as

$$C_m(i,j)=C_{L1}(i,j)\cdot C_{L2}(i,j)\cdot C_{L3}(i,j),$$
$$\text{where } C_{Li}(i,j)=\left\| \mu_1^{Li}(i,j) \right| - \left| \mu_2^{Li}(i,j) \right\|,\ i=1,2,3. \quad (6)$$

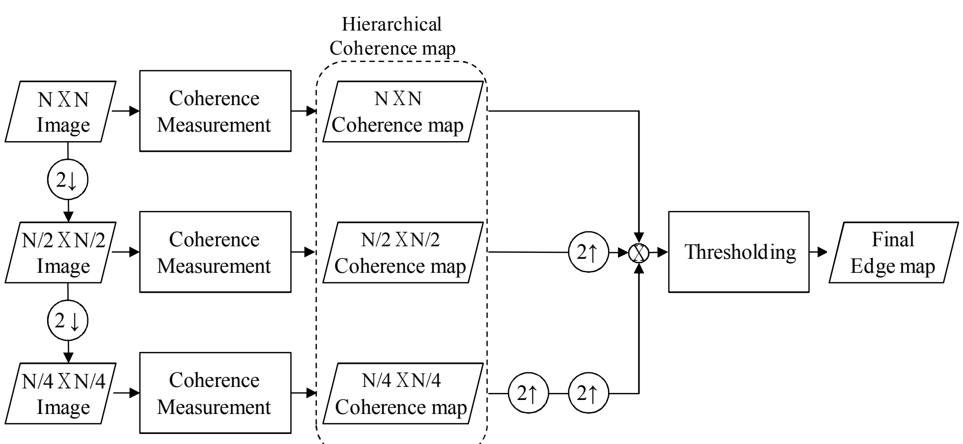



Fig. 3. The procedure of the enhanced edge map by multi-resolutional coherence measurement

In Eq (6), $C_m$ means coherence map by the multi-resolution images. $C_{L1}$, represent coherence maps of the original resolution image. And $C_{L2}$, and $C_{L3}$ represent up-sampled images of $LL_1$ sub-band image by 1-level wavelet decomposition, and $LL_2$ sub-band image by 2-level wavelet decomposition, respectively. The coherence map of the low resolution image represents the connected and relatively noiseless edges. By considering more neighbor pixels in measuring coherence values, it is possible to reduce noisy edges, which can be done by calculating coherence values in lower resolution image; however, it is difficult to get fine edge.

By using hierarchical coherence maps, the robust and linked edge information could be obtained from lower resolution images and edge details from the original resolution image. Thereby, $C_m$, coherence map that is the products of hierarchical coherence maps has higher value in edge region and has lower value in noise area. Finally, the enhanced edge map, $E_e$, is obtained as follows,

$$E_e(i,j) = 1,\ \ if\, C_m(i,j) > \lambda_{mc}. \tag{7}$$

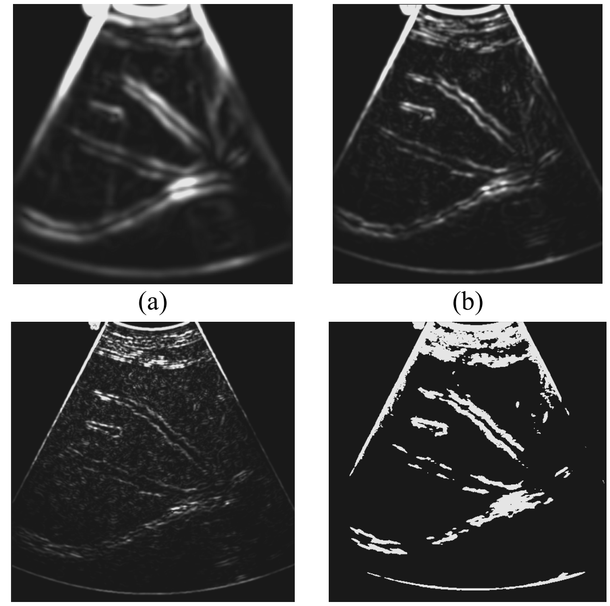
where $\lambda_{mc}$ is the predefined threshold value for the final edge map.

## IV. Experimental Results

The efficiency of the proposed method was verified by experiments with medical ultrasound images. The ultrasound image was obtained from General Electronics (GE), which contains a liver area. Its depth of pixel is 8bits/pixel. The thresholding parameter in the enhanced edge map, $\lambda_{mc}$, is 40, which were chosen empirically.

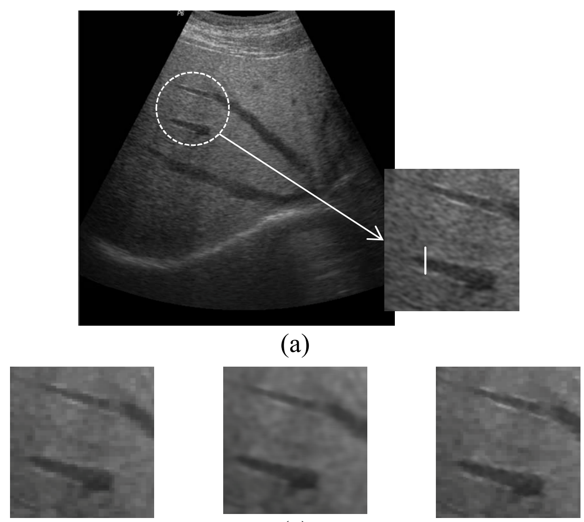
Figure 4 illustrates the hierarchical coherence maps and the enhanced edge map by the proposed method of Fig 2 (a). As shown in Fig. 4, the coherence map of the lower resolution image represents the linked edges with relatively less noise whereas the coherence map of the higher resolution image contains edge details. The enhanced edge map by these hierarchical coherence maps is shown in Fig. 4 (d), which illustrates the robust and linked edges without noise. As seen in Fig. 4 (d), most important edges in the image are clearly observed, which could guarantee that the proposed method is able to detect important edges in most cases.

Figure 5 and 6 shows the results of adaptive wavelet Bayes Shrinkage using the enhanced edge map by multi-resolutional coherence measurement and the previous works for speckle noise reduction: the previous wavelet Bayes Shrinkage and speckle reducing anisotropic diffusion (SRAD).



(a) (b) (c) (d)

Fig. 4. The hierarchical coherence maps and the enhanced edge map of Fig 2 (a): (a) coherence map $C_{L3}$, (b) coherence map $C_{L2}$, (c) coherence map $C_{L1}$, and (d) the enhanced edge map



(a) (b) (c) (d)

Fig. 5. The comparison of the experimental results in details: (a) original image, (b) Wavelet Bayes Shrinkage, (c) SRAD, and (d) proposed method.

SRAD in Fig. 5 (c) reduces speckle noise effectively but overly smoothing in edge details and the previous wavelet Bayes Shrinkage in Fig. 5 (b) is also ambiguous in boundary, while the proposed adaptive wavelet Bayes shrinkage using multi-resolutional coherence measurement shows outstanding results with preserving edges and details. In Fig. 6, the proposed method also shows the superior noise reduction result with keeping edge details.

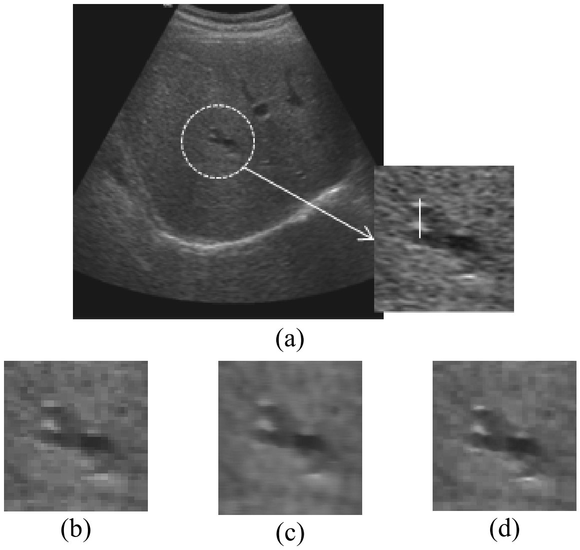



Fig. 6. The comparison of the experimental results in details: (a) original image, (b) Wavelet Bayes Shrinkage, (c) SRAD, and (d) proposed method.

Figure 7 and 8 illustrate the cut view of each result in Fig. 5 and 6 whose position are depicted as the vertical directional solid line in Fig. 5 (a) and Fig. 6 (a), respectively. These regions contain the part of the blood vessel which shows the characteristic of the obvious boundary whose contrast is higher than that of the neighbors.

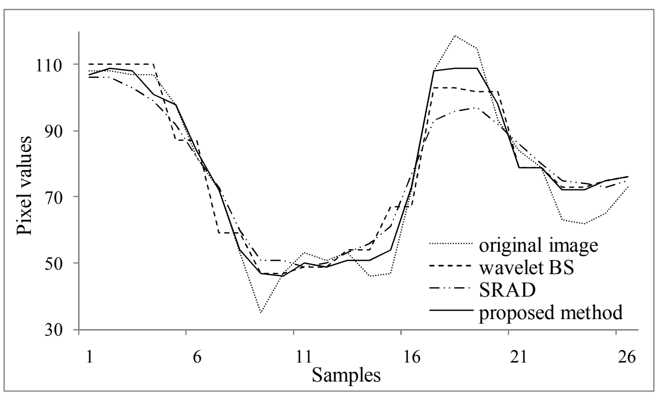



Fig. 7. The cut views of the each result in Fig. 5

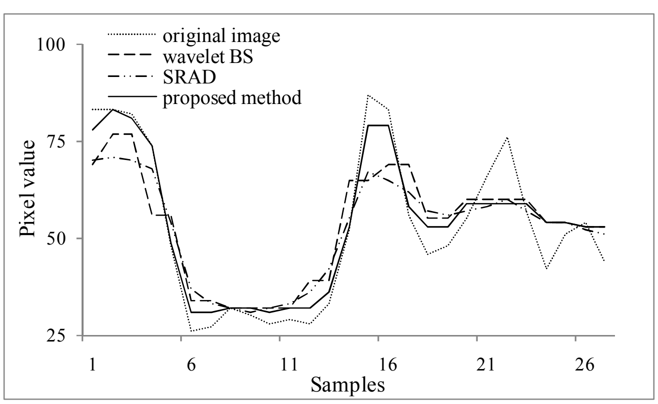



Fig. 8. The cut views of the each result in Fig. 6

As seem in Fig. 7 and 8, the proposed method shows the effective speckle noise reduction with preserving boundaries in edges, whereas the results of the previous wavelet Bayes shrinkage and SRAD illustrates vague boundaries in edges by overly smoothing.

## V. Conclusions

Ultrasound images are degraded by speckle noise that reduces the contrast and details of images. The effective method for speckle noise reduction with keeping edge has still been a challenging point. To prevent the loss of detailed information by over smoothing, adaptive wavelet based-speckle noise reduction by the enhanced edge map using multi-resolutional coherence measurement is proposed. The proposed enhanced edge map showed the noiseless and the connected edge information. In addition, the efficiency of adaptive wavelet Bayes shrinkage with enhanced edge map was verified by the experimental results comparing with the conventional method.

## References

[1] O. Michailovich and A. Tannenbaum, "Despeckling of medical ultrasound images," *IEEE Trans. Ultrason. Ferro. Freq. Control*, vol. 53, No.1, pp. 64-78, 2006.

[2] S.Sudha, G.R.Suresh, and R.Sukanesh, "Comparative study on speckle noise suppression techniques for ultrasound images," *International Journal of Engineering and Technology*, vol. 1, no. 1, pp.57-62, 2009.

[3] Y.Yongjian and S.T.Acton, "Speckle reducing anisotropic diffusion," *IEEE Trans. Img. Proc.*, vol.11, no.11, pp.1260-1270, 2002.

[4] K.Z. A.Elmoniem, A.B. Youssef, and Y.M. Kadah, "Real-time speckle reduction and coherence enhancement in ultrasound imaging via nonlinear anisotropic diffusion," *IEEE Trans. Biomed. Eng.* vol.49, no. 9, pp.997-1014, 2002.

[5] S.Gupta, R.C.Chauhan, and S.C.Sexana, "Wavelet-based statistical approach for speckle reduction in medical ultrasound images," *Med. Bio. Eng. Comput*, vol. 42, no.2, pp. 189-192, 2004.

[6] J. Weikert, "Anisotropic diffusion in image processing," Ph. D thesis, University of Kaiserslautern, Germany, 1996.

[7] Y.S. Kim and J.B. Ra, "Improvement of ultrasound image based on wavelet transform: speckle reduction and edge enhancement," in *Proc. SPIE medical imaging 2005*, vol. 5747, pp. 1085-1092, 2005.

[8] Y.Guo, H.D.Cheng, J.Tian, and Y.Zhang, "A novel approach to speckle reduction in ultrasound," *Ultrasound in Med. & Biol.*, vol. 35, no. 4, pp. 628-640, 2009.

[9] D.Kroon and C.H.Slump, "Coherence filtering to enhance the mandibular canal in cone-beam CT data," *IEEE-EMBS Benelux Chapter Symposium 2009*.