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Foveated Nonlocal Means Despeckle Filtering for Ultrasound Imaging: Imaging Perspective

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***Abstract*—Ultrasound speckle noise degrades imaging contrast and hides anatomical details; thus causing inaccuracy in clinical diagnosis. Although speckle reduction methods such as classical nonlocal means (NLM), optimized Bayesian nonlocal means (OBNLM), and speckle reducing anisotropic diffusion (SRAD) filters have been proposed for years, they still suffer two major problems – insufficient preservation of characteristic details such as calcifications and inordinate blurring making image appearance artificial. To solve the two problems, we propose a novel foveated nonlocal means despeckle filtering technique, inspired by the human visual system. Conventional NLM filters despeckle via searching for analogous patches at different areas within the image and then estimating the impulse response by the degrees of similarity appraised by a windowed Euler distance between the target and searching patches. In our technique, foveated self-similarity is used instead of conventional self-similarity. The foveated self-similarity is based on a new patch operator mimicking human retina properties, sharpening patch pixels in the center and blurring them near the periphery. Moreover, throughout the literature, the tuning of the search window and patch sizes and other parameters are not consistent; nonetheless, in this study, they are tuned universally from imaging perspective, i.e., according to the size of point spread function which allows the adaption to different imaging systems and settings. Simulations and clinical data (not shown here) were used to verify our proposed method. The performance of our proposed method is also compared with the classical despeckle filters. The results demonstrate that the proposed technique can remove speckles forcefully while more effectively retaining structural edge details, textures, and point-like structures. Quantitative measures such as contrast-to-noise ratio, edge preservation index and contrast measure are also presented.**

Keywords—speckle reduction, nonlocal means filter, foveation, self-similarity, point spread function.

I. Introduction

One of Ultrasound image characteristics is speckle noise. It reduces imaging contrast limiting the applications of medical computer vision techniques such as automatic detection and segmentation of lesion regions and causing inaccuracy in clinical diagnosis. Hence, various speckle reduction methods have been suggested in recent years, such as optimized Bayesian nonlocal means (OBNLM) filter [1] and speckle reducing anisotropic diffusion (SRAD) filter [2]. However, they still suffer two critical problems:

i. Inadequate preservation of specific details including textures point-like structures, and structural outline.
ii. Excessive blurring making image semblance artificial.

To solve these two problems, here we propose a novel foveated nonlocal means filtering technique, inspired by the system of human vision, for speckle reduction in ultrasound imaging. Classical nonlocal means(NLM) filters [3] despeckle via searching for similar patches at different areas within the image and then estimating the weighting by the degrees of analogy appraised by a windowed Euclidean distance between the target and searching patches. According to NLM, in our technique, foveated self-similarity nonlocal means (Fov-NLM) [4] filter introduces a foveation operator to preprocess each patch and calculates patch similarity by the foveated distance (replacing Euclidean distance in NLM). It allows patch weighting to mimic human retina properties, i.e., sharper when approaching the center and blurred near the periphery. When finding similarity between patches, the speckle patterns within the two patches play an important role, and the size of each speckle and the pattern are related to the imaging point spread function. Therefore, in this paper, the patch size and search window size used in our proposed technique is all defined as a multiple of the point spread function (PSF) size of the imaging system, instead of number of pixels, linking the imaging perspective with the despeckle algorithm.

II. Materials and Methods

A. Specklel model

J.W. Goodman in 1976 proposes speckle noise can be regarded as multiplicative noise [5]. For the sake of seeing weak signals in the image, most ultrasound imaging systems use logarithmic conversion to compress the envelope-detected echo signal. After logarithmic compression, the multiplicative speckle noise is transformed into additive noise. Because of this, in this paper, the logarithmic compressed data is used as the input of our proposed despeckle algorithm.

B. Non-local means filter

A. Buades proposed classical NLM filter which is a pixel-wise adaptive neighborhood filter. It focuses on noise removal and has an excellent efficiency of noise reduction.

First, giving a discrete noisy image z(x):

$$z(x)=y(x)+\eta(x) \quad x\to R \quad x\in X\subset Z^2 \qquad (1)$$

, where Z^2 is the image domain, y(x) is an unknown original noise free image, and η is additive noise.

Because single-pixel cannot be used for similarity estimation, target pixel and its neighbor pixels are used to form a "patch" for similarity estimation as shown in the following equation:

$$z_x(u)=z(u+x) \qquad u\in U\subset Z^2 \qquad (2)$$

According to NLM basic implementation, the speckle-reduced image $\tilde{y}$ at pixel xi is calculated as a weighted average of a set of pixels in the image, and it is defined as:

$$\tilde{y}(x_i)=\sum_{x_j\in X} w(x_i,x_j)\, z(x_j) \qquad \forall x_i\in X \qquad (3)$$

, where w (x_i, xj) means the set of adaptive weighting that depend on the similarity between pixel x_i and x_j. If two patches are with high similarity, then the weighting is high, and vice versa (also need to normalize):

$$w(x_i,x_j)=e^{-\frac{d(x_i,x_j)}{h^2}} \Big/ \sum_{x\in X} e^{-\frac{d(x_i,x)}{h^2}} \qquad (4)$$

, where h^2 is a parameter to control the decay of the exponential function; d (x_i, x_j) is the Euclidean norm used to measure the similarity between patches centered at x_i and x_j:

$$d(x_i\,,\,x_j)=\left\| (z_{x_i}-z_{xj})^2\boldsymbol{k} \right\|_1=\sum_{u\in U}(z(u+x_i)-z(u+x_j))^2\,\boldsymbol{k}(u) \qquad (5)$$

, where ***k*** is a non-negative window kernel on U where Gaussian kernel with a fixed standard deviation is generally used.

The NLM filtering procedure is illustrated in Fig. 1.

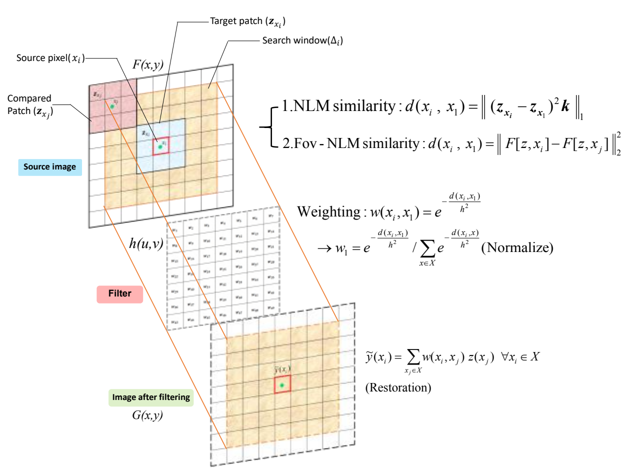

Fig. 1 Illustration of the classic NLM filtering and the proposed Fov-NLM filtering.

C. Foveated self-similarity nonlocal means filter(Fov-NLM)

In the human visual system, the retinal image is sharp at the center of gaze (fixation point) and become gradually blurred when the distance increased from the gaze center. Such phenomenon is called "foveation". That is, when the human visual system judges the similarity between image patches, foveated patches instead of the original patches are used for the comparison. Inspired by such a comparison scheme in our human visual system, here a foveation operator is used to introduce the foveated effect on the two patches used for similarity estimation in NLM filtering.

Then, we adopt foveated distance to replace Euclidean distance in equation (5):

$$d(x_i,x_j)=\| F[z,x_i]-F[z,x_j] \|_2^2, \qquad (6)$$

where F [• , x] means foveated patch, as illustrated in Fig. 2.

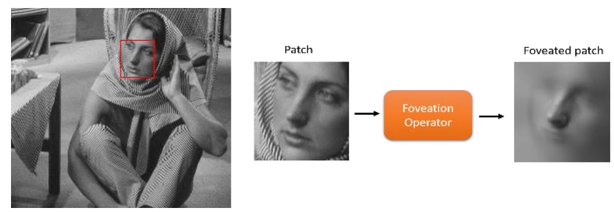

Fig.2 Illustration of fovated patch processed with a foveation operator.

Here foveation can be constructed by several cascaded space-variant procedures, and can be viewed as an spatial variant filtering. Note that the main difference between the classical NLM filter and the proposed Fov-NLM filter is the approach to measure the similarity between patches, as shown in equations (5) and (6) and illustrated in Fig.1. We believe that such foveated self-similarity can be the key to solve the two major problems of the classic NLM filters described in the Introduction section.

III. Simulation Results

In the simulation, we adopt some evaluation metrics to compare the performance among different speckle-reduction algorithms, including the contrast-to-noise ratio (CNR) [6], contrast measure (CM) [7] and edge preservation index (EPI) [8]:

i. CNR: Measure of the ability of speckle reduction. (larger value means the better ability)

ii. CM_{homo}: The performance of despeckling in the homogeneous areas. (smaller value means better the performance)

iii. CM_{edge}: The efficiency of detail characteristic reserving. (larger value means the better efficiency)

iv. EPI: The capability of reserving edge of the main structure and speckle reduction. (larger value means the better capability)

The above indices are used to estimate the performance of our Fov-NLM filters and classical NLM, ONNLM, and SRAD filters. The result is shown in Fig.3 and Table.1. (average of measures from twenty data)

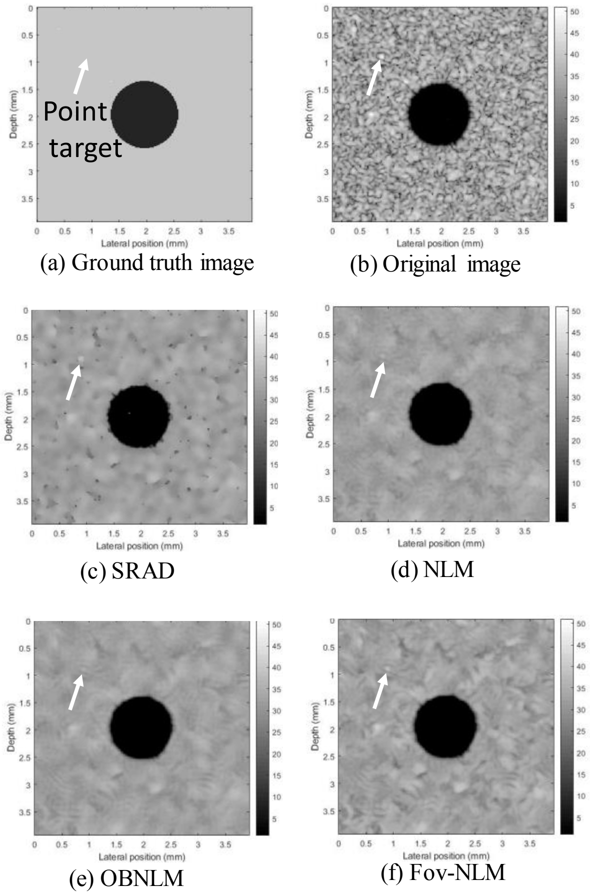

Fig. 3 Original image and the speckle-reduced images with different algorithms.

Fig. 3 shows the results with different algorithms. SRAD (Fig.3. (c)) possess good performance in speckle reduction. However, the edges and point-like structures appear blurred. The NLM (Fig. 3(d)), OBNLM (Fig. 3(e)) and proposed Fov-NLM (Fig. 3(f)) filters also have good enough performance in despeckling along with reserved detail, but the point target (indicated by an arrow in the images) in the Fov-NLM filtered image is the clearest. In terms of the performance of retaining details, the proposed Fov-NLM filter is better than the classical NLM and OBNLM filters. The same conclusion can be drawn from Table 1.

TABLE I. IMAGE QUALITY METRICS FOR SIMULATION IMAGES

Algorithmic	**CNR**	**CM_{homo}**	**CM_{edge}**	**EPI**
Original	7.4132	15.7324	74.9800	0.4073
SRAD	20.5549	1.9081	23.0469	0.5531
NLM	22.2097	1.5556	15.6189	0.5613
OBNLM	**23.3260**	**0.4587**	13.6518	0.5488
Fov-NLM	17.8967	1.7581	**26.1016**	**0.5857**

*Parameter setting: SRAD (Iteration:150, Time step: 0.2); NLM (Patch size: 2x PSF,Search size:4x PSF); OBNLM(Patch size: 2x PSF,Search size:4x PSF); Fov-NLM(atch size: 2x PSF,Search size:4x PSF)

IV. Conclusions

In this paper, a novel foveated nonlocal means despeckle filtering technique, inspired by the human visual system, is proposed. Simulations and clinical data (results are not shown here) were used to verify the proposed method, showing that our proposed technique can remove speckles effectively while preserving the details and edges – outperforming the state-of-the-art approaches.

V. Acknowledgements

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