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A simulation study on comparison of singular value decomposition filtering in pre- and post-beamforming

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1. Introduction

Cardiac and cerebrovascular diseases are the leading causes of death, and arteriosclerosis is one of the substantial causes. Examination with a diagnostic ultrasound device is suitable for early detection of arteriosclerosis. The examination is performed by obtaining ultrasonic frame data from the arterial vessels and evaluating blood flow echoes from the B-mode image.

Clutter filtering is essential to visualize blood flow echoes by suppressing the surrounding tissue echoes (clutter signal) in ultrasound frame data acquired from the vasculature. Our research group has studied blood flow echo simulation under various ultrasound transmission and reception sequences, but mainly did not consider the clutter signal[1)]. In this study, we aim to establish an environment for blood flow echo simulation that takes the clutter signal into account for detailed analysis with grating lobe artifact and tissue motion.

Beamforming can be used to image the received ultrasound data, and it is desirable to suppress unwanted echo components as early as possible in the signal processing process. We have previously reported that the image quality index (contrast) of B-mode images of the in vivo jugular vein was improved by filtering in pre-beamforming (receiver element data) (proposed method) and by comparing the results of filtering in post-beamforming (conventional method)[2)]. We validated of the proposed method on simulated data to optimize the signal processing process of the filter processing for image enhancement and accurate velocity estimation.

2. Methods

2.1 Simulation condition

Scatter models of tissue, blood, and vessel walls were created. The tissue was a rectangular body with 30 mm range, 8.0 mm slice, and 60 mm width, within which a vessel portion with 3.0 mm radius and a vessel wall with 1.0 mm radius were placed. The number density of scatterers was approximately 20 points/mm^3, and the scattering intensity was set to 100 for the tissue and 200 for the vessel wall when blood was set to 1. The scatterer in the blood portion gives a parabolic velocity distribution at the maximum of 600 mm/s, while the other portions are stationary. 500 plane waves at 5 consecutive angles (-10, -5, 0, 5, 10°) were transmitted and received in total using Field II[2,3)], and channel data were generated. The ultrasound transmission interval was 96 μs.

2.2 Singular value decomposition (SVD)

Both methods create a spatiotemporal matrix **S** with dimensions (N_m,N_n), respectively, where N_n is the number of packets, and N_m is different for each method and is shown below.

$$N_m = N_x \times N_z. \tag{1}$$

$$N_m = N_i \times N_t. \tag{2}$$

The data dimension in the conventional method is $N_x \times N_z$, i.e., the product of the number of sampling points in the azimuth and range directions, while the data in the proposed method consists of N_i receiving element channels and N_t sampling points of the received signal for each element. SVD is performed on the obtained spatiotemporal matrix **S**.

$$\mathbf{S} = \mathbf{U}\mathbf{\Sigma}\mathbf{V}^T, \tag{3}$$

where **U** is a spatial singular vector, **V** is a temporal singular vector, **Σ** is a diagonal matrix of singular values in descending order, and T denotes a transpose. The proposed method processes the matrix of channel data in pre-beamforming, whereas the conventional method processes the matrix in post-beamforming. To obtain the graph of singular values, the obtained matrix of singular values **Σ** was dB-transformed as

$$Power = 20\log_{10}\frac{\mathrm{diag}(\mathbf{\Sigma})}{\max\left(\mathrm{diag}(\mathbf{\Sigma})\right)}, \tag{4}$$

where diag(**Σ**) is the diagonal component of the diagonal matrix. Two threshold values (low- and

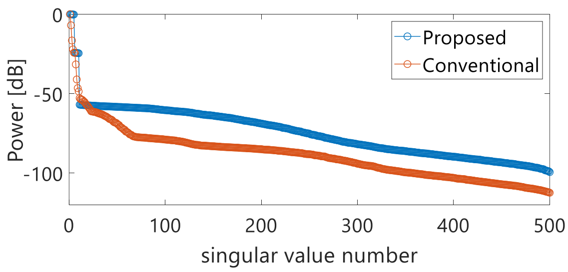

Fig. 1 Singular value distributions for the conventional (orange) and proposed (blue) methods.

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high-rank thresholds) are determined based on the inflection point from the power at each singular value rank.

The singular value distributions of both methods are shown in **Fig. 1**. The first inflection point (low-rank threshold) was confirmed at around −55 dB in both methods. It was difficult to set the high-rank threshold according to the inflection point because the noise component was not composed. The components between clutter and blood flow are more dominant in the low-rank band, and the inclusion of the high-rank band has low echogenicity on the B-mode image. Therefore, in this study, the filter was processed by setting the high-rank threshold to 500, which is the maximum singular value number.

3. Results

Fig. 2 shows the B-mode image before filtering and those processed by both filter methods. Both methods showed that the blood flow echoes were visualized by filtering process. Compared to the conventional method, the proposed method suppressed the clutter component better especially in the upper region of vessel lumen. **Table I** summarizes the mean and standard deviation (SD) of contrast in each frame. Also, the scores of the previous in vivo study[2] in human jugular veins are shown. Corresponding to the B-mode image, the mean of contrast was enhanced by the proposed strategy from several to 10 dB against the conventional strategy. In addition, the SD of contrast was slightly different in the simulation study.

Table I Results of mean and SD of contrast in each frame.

	Conventional	Proposed
Mean of contrast (Simulation)	38.2 ± 2.3 dB	50.1 ± 1.1 dB
Mean of contrast (in vivo vein [2])	10.7 ± 3.6 dB	18.3 ± 4.6 dB
SD of contrast (Simulation)	8.45 ± 0.37 dB	8.44 ± 0.23 dB
SD of contrast (in vivo vein [2])	3.78 ± 0.69 dB	3.07 ± 0.74 dB

4. Conclusion

In this study, an environment for blood flow echo simulation that takes clutter signals into account was established, and optimization of the clutter filtering process was investigated. It was shown that filtering in pre-beamforming can suppress clutter components better than filtering in post-beamforming. In future works, the performance on the phantom dataset and effect of tissue motion will be investigated.

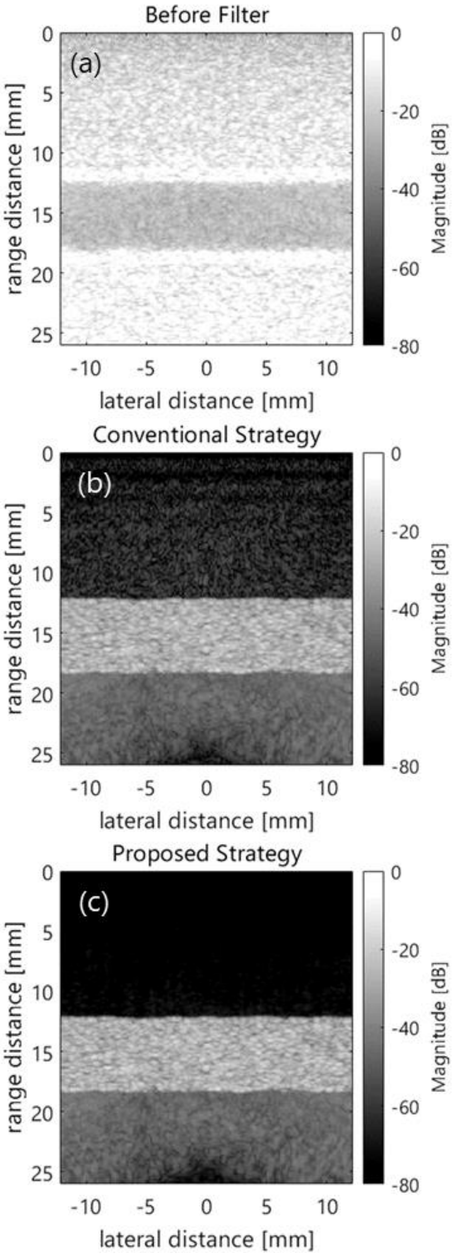

Fig. 2 Analysis results of simulation data. (a)-(c) B-mode image without filter, with conventional filter strategy, and proposed strategy.

References

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