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Investigation on singular value decomposition filter for extraction of reflected signals from blood flow in veins
静脈における血流からの反射エコー抽出のための特異値分解フィルターに関する検討

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1. Introduction

Color Doppler techinique in ultrasonography is used for diagnosis of cardiovascular diseases. Meanwhile, echo signals from blood flow itself can be visulized by combining high frame rate ultrasound imaging with singular value decomposition (SVD) based clutter filter [1-6].

Commonly, the SVD-based clutter filter is applied to beamformed RF signals. Also, in our previeous measurement of a heart [5], the clutter filter was applied to signals received by channels connected to transducer elements (element signals), and then image quality such as contrast-to-noise ratio (CNR) was compared. As a result, the image quality metrics obtained by applying the SVD-based clutter filter to the beamformed signals were superior in the measurements of the heart. This was because the masurement area of the heart was wider in both the depth and lateral directions and point spread function (PSF) of the imaging system differed spatially.

In this study, the image quality was examined when the SVD-based clutter filter is applied to element signals in measurements of veins, which exist near skin surface.

2. Material and Methods

In this section, the procedure of the SVD-based clutter filter is briefly described [1-6]. First, let us define the beamformed signal at position (x, z) in slow time (frame) n as $s_b(x, z, n)$ and element signal received at channel i as $s_e(i, t, n)$, where variable t represents the time (fast time) corresponding to the distance from the element when it is multiplied by a half of speed of sound c. Then, the spatiotemporal matrix $\boldsymbol{S}$ is created by rearranging the beamformed signals $s_b(x, z, n)$ of dimensions (N_x, N_z, N_n) or element signals $s_e(i, t, n)$ of dimensions (N_i, N_t, N_n) to a 2-D matrix with dimensions $(N_x \times N_z, N_n)$ or $(N_i \times N_t, N_n)$, respectively. Also, variables N_x, N_z, N_n and N_t are the number of sampling points in the lateral, depth, frame, and fast-time directions, respectively. Additionally, variable N_i represents the number of receive channels. The spatiotemporal matrix $\mathbf{S}$ can be decomposed into a product of three matrices using the SVD as

$$\mathbf{S} = \mathbf{U\Sigma V}^{\mathrm{T}}, \quad (1)$$

where matrices $\mathbf{U}$ and $\mathbf{V}$ are composed of spatial and temporal singular vectors, respectively. Also, matrix $\mathbf{\Sigma}$ is composed of singular values in a descending order. In the SVD-based clutter filtering, echo signals from moving blood cells can be obtained by replacing the singular values of the matrix $\mathbf{\Sigma}$ at lower and higher order components with zero. In this paper, the low order threshold was chosen based on the amplitudes of the singular values, and the threshold value was set to -62 dB. Also, the high order threshold was chosen based on the slope of the profile of the singular values.

In the measurements, the high temporal resolution was achieved using plane-wave-based ultrasonic imaging. The repetition frequency of the plane waves was set to 96 μs, which corresponding to a frame rate of 10.4 fps. The packet size in clutter filtering was set to 1024 frames, and each temporal ensemble window was shifted by a half of the packet size. In this study, the qualities of the images obtained by applying the SVD-based clutter filter to the beamformed signals was compared with those obtained by applying the clutter filter to the element signals in measurements of veins. **Fig. 1** shows flow charts of the conventional and proposed strategies. Contrast of the signals from the blood flow was used as an evaluation index for this comparison and was defined as

$$\text{contrast} = \mu_{\mathrm{bf}} - \mu_{\mathrm{t}}, \quad (2)$$

where variables μ_{bf} and μ_{t} are the mean amplitudes in regions of the blood flow and tissue (including noise), respectively.

3. Results and Discussions

Fig. 2 shows a blood flow image of the vein obtained by applying the SVD-based clutter filter to the beamformed signals. Red and blue dotted squares were ROIs of the blood flow and tissues for

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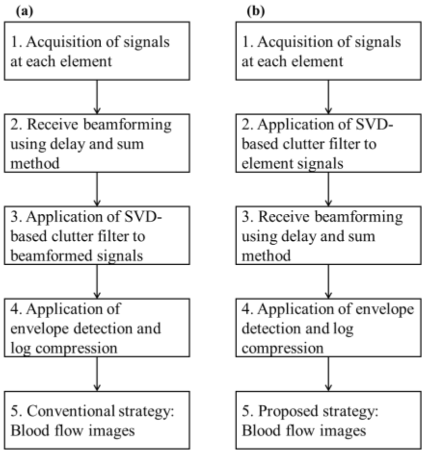

Fig. 1 Flow charts of two strategies. (a) Conventional strategy and (b) proposed strategy.

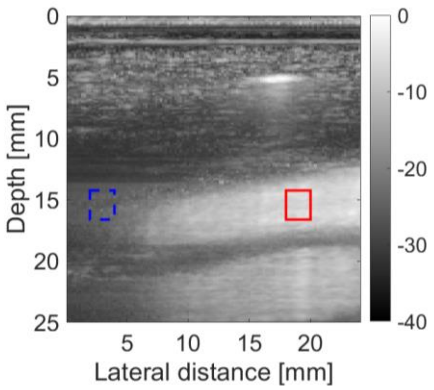

Fig. 2 Blood flow image obtained by applying the clutter filter to the beamformed signals.

calculation of the contrast, respectively. Also, **Fig. 3** shows a comparison of the blood flow images obtained by applying the SVD-based clutter filter to the beamformed signals (a) and element signals (b) at the same phase. By qualitatively evaluating these flow images shown in Fig. 3, the speckle pattern in Fig. 3(b) was more uniform than that in Fig. 3(a).

Fig. 4 shows the contrasts obtained by applying the clutter filter to the beamformed signals (blue line) and element signals (red-dotted line) for one cardiac cycle (0.7 s). The contrasts obtained by applying the filter to the beamformed and element signals for one cardiac cycle were 17.8 ± 1.23 dB and 18.8 ± 0.93 dB, respectively. Consequently, the contrast was improved by applying the SVD-based clutter filter to the element signals.

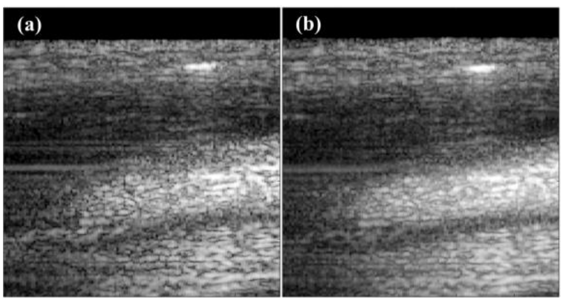

Fig. 3 Comparison of blood flow images obtained by applying the clutter filter to the beamformed signals (a) and element signals (b) in the same phase.

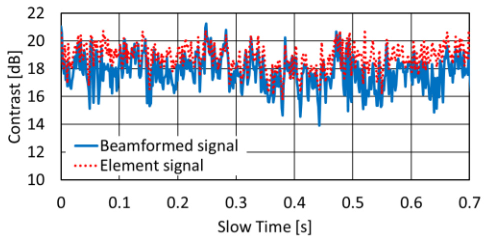

Fig. 4 Contrasts obtained by applying the clutter filter to the beamformed signals (blue line) and element signals (red-dotted line) for one cardiac cycle (0.7 s).

4. Conclusion

In this study, the image quality of the blood flow image obtained by applying the SVD-based clutter filter to the beamformed signals was compared with that obtained by applying the clutter filter to the element signals in measurements of veins. The contrast of the blood flow image was used as the evaluation index for this comparison, and the contrast was improved from 17.8 ± 1.23 dB to 18.8 ± 0.93 dB by applying the SVD-based clutter filter to the element signals.

We will investigate a difference in the speckle patterns obtained by applying the clutter filter to the beamformed and element signals quantitatively.

References

1. C. Demené, T. Deffieux, M. Pernot, B. F. Osmanski, V. Biran, J. L. Gennisson, L. A. Sieu, A. Bergel, S. Franqui, J. M. Correas, I. Cohen, O. Baud and M. Tanter: IEEE Trans. Med. Imag. **34** (2015) 2271.
2. P. Song, A. Manduca, J. D. Trzasko and S. Chen: IEEE Trans. Med. Imag. **36** (2017) 251.
3. H. Ikeda, R. Nagaoka, M. Lafond, S. Yoshizawa, R. Iwasaki, M. Maeda, S. Umemura and Y. Saijo: Jpn. J. Appl. Phys. **57** (2018) 07LF12.
4, J. Baranger, B. Arnal, F. Perren, O. Baud, M. Tanter and C. Demené: IEEE Trans. Med. Imag. **37** (2018) 1574.
5. M. Mozumi, R. Nagaoka and H. Hasegawa: Jpn. J. Appl. Phys. **58** (2019) SGGE02.
6. H. Hasegawa, R. Nagaoka, M. Omura, M. Mozumi and K. Saito: J. Med. Ultrason. **41** (2014) 151.