2P5-1

Estimation of transmit-receive response of ultrasound system for high range resolution imaging

高距離分解能イメージングのための超音波装置の送受信特性の推定

Michiya Mozumi[1], Hideyuki Hasegawa[2†]
([1]Faculty of Engineering, University of Toyama; [2]Graduate School of Science and Engineering for Research, University of Toyama)
茂澄倫也 [1], 長谷川英之 [2†] ([1] 富山大 工, [2] 富山大院 理工)

1. Introduction

The spatial resolution is the main factor which determines quality of a B-mode image. The accuracy of morphological diagnosis by ultrasonography depends on the spatial resolution. The range resolution, which represents the spatial resolution along the ultrasound beam, is in general determined by the characteristic of the transducer. Many studies, which improve the range resolution without replacing the transducer elements, were conducted [1,2]. These methods work as an inverse filter to broaden the frequency bandwidth of the received ultrasound signal.

To improve the range resolution, our group developed a method based on the maximum likelihood (ML) method to estimate the scattering strength distribution inside an imaging target [3]. However, this method doesn't consider the ultrasound attenuation during propagation. In the present study, we estimated the transmit-receive response of a diagnostic ultrasound system from echoes of an imaging target to reduce the influence of the difference in propagation media.

2. Materials and Methods

In this section, we introduce a filter described in Ref. [3]. By assuming that the noise contained in the received signal is Gaussian, the likelihood function is expressed as follows:

$$p_n(\mathbf{s}_n|\mathbf{z}) = \frac{1}{\det(\pi\mathbf{K})}\exp\{-(\mathbf{s}_n - \mathbf{Hz})^{\mathrm{H}}\mathbf{K}^{-1}(\mathbf{s}_n - \mathbf{Hz})\},$$

where $\mathbf{s}_n$, $\mathbf{K}$, and $\mathbf{z}$ are a signal received by a transducer element, the covariance matrix of the signal, and scattering strength distribution. The matrix $\mathbf{H}$ is the transmit-receive response given by:

$$\mathbf{H} = \begin{bmatrix} h_0 & 0 & 0 & \cdots & 0 \\ h_1 & h_0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ h_{M-1} & h_{M-2} & h_{M-3} & \cdots & h_0 \\ \vdots & \vdots & \vdots & \vdots & h_1 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ h_{K-1} & h_{K-2} & h_{K-3} & \cdots & h_{K-M} \end{bmatrix}.$$

----

†hasegawa@eng.u-toyama.ac.jp

On the basis of the least square method, $\hat{\mathbf{z}}$, which maximize the likelihood, is obtained as follows:

$$\hat{\mathbf{z}} = \frac{\mathbf{H}^{\mathrm{H}}\mathbf{K}^{-1}\mathbf{s}_n}{\mathbf{H}^{\mathrm{H}}\mathbf{K}^{-1}\mathbf{H}} = \frac{\mathbf{K}^{-1}\mathbf{H}}{\mathbf{H}^{\mathrm{H}}\mathbf{K}^{-1}\mathbf{H}} \cdot \mathbf{s}_n.$$

The transmit-receive response $\mathbf{h} = (h_0, h_1, \cdots, h_{K-1})$, which is an element of matrix $\mathbf{H}$, is commonly obtained from the point spread function (PSF). The PSF obtained as a spread of an echo signal when a point scatterer is imaged, and the PSF is typically measured using an echo from a fine wire placed in water. When the PSF measured in such a situation is used as the transmit-receive response and applied to the filter, the performance of the filter may degrade. For instance, when a PSF obtained from a fine wire in water is used for imaging of a living tissue, the performance of the filter will degrade because of the difference in propagation media. To reduce such an influence of the propagation medium, we estimated $\mathbf{h}$ from echo signals from an imaging target as follows:

$$\mathbf{S}' = \frac{1}{N_{\mathrm{RF}}}\sum_{i=0}^{N_{\mathrm{RF}}-1}\mathbf{S}_i,$$

where $\mathbf{S}_i$ is the amplitude spectrum of the signal received by the i-th transducer element and N_{RF} is the number of signals. In the amplitude spectrum $\mathbf{S}_i$ received by each element, many dips occur due to interference among echoes, and such an amplitude spectrum cannot be not used as the transmit-receive response [2]. From the fact that scatters are distributed randomly in tissue, it is desirable to obtain the transmit-receive response from the averaged amplitude spectrum $\mathbf{S}'$. An estimate of the transmit-receive response $\mathbf{h}$ was obtained by using inverse Fourier transformation on $\mathbf{S}'$. In the present study, this procedure to estimate $\mathbf{h}$ was done region by region to consider frequency dependent attenuation, and estimated $\hat{\mathbf{h}}$ was used for imaging of the corresponding region.

The transmit-receive sequence is described in Ref. [4]. To perform parallel beamforming, plane waves were emitted using 96 transducer elements, then 24 receiving beams were created in response to one emission.

3. Experimental Results

To evaluate the performance of the proposed method, we compared a B-mode image of a phantom obtained by the proposed with other methods. **Figures** 1(a), 1(b), and 1(c) show B-mode images of a wire phantom without filtering, with the filter using the PSF obtained from a wire placed in water, and with the filter using the proposed method, respectively. In the phantom for this experiment, point targets were placed at different axial depths. In Fig. 1, dynamic ranges (DR) of B-mode images are controlled so that the seeing of B-mode images become similar.

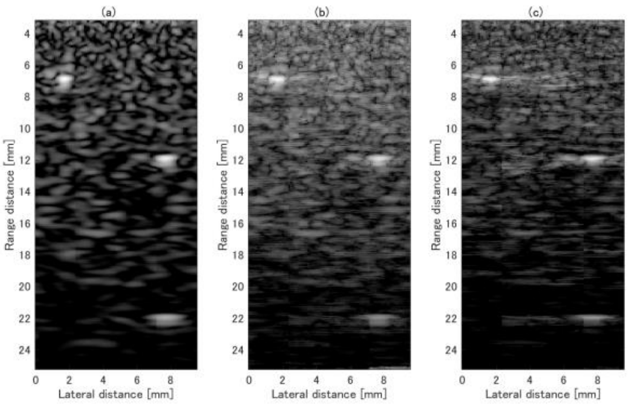

Fig. 1: B-mode images of wire phantom obtained with conventional DAS beamforming. (a) without filter (DR: 30 dB), (b) with filter using PSF obtained from fine wire placed in water (DR: 80 dB), and (c) with filter using proposed method (DR: 80dB).

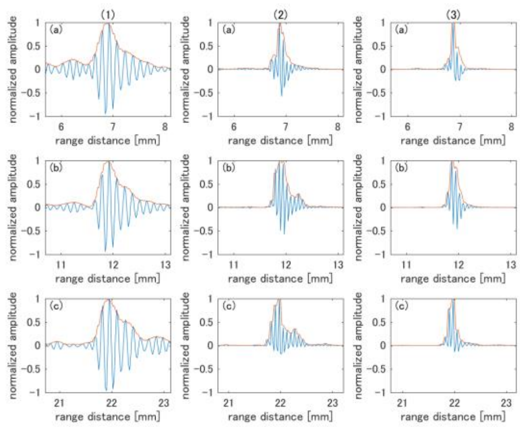

Fig. 2: RF signals at an axial depth of (a) 7 mm, (b) 12 mm, and (c) 22 mm in B-mode images shown in Fig. 1. (1) Conventional image. (2) with filter using PSF obtained from wire placed in water and (3) with filter using the proposed method.

Figure 2 shows radio frequency (RF) signals in scan lines where the point target exists in Fig. 1. Figs. 2(1a) - 2(1c), 2(2a) - 2(2c), and 2(3a) - 2(3c) were obtained from B-mode images shown in Figs. 1(a), 1(b), and 1(c), respectively.

In Figs. 2(3a) - 3(3c), the axial pulse widths, which influence the range resolution, become shorter by the proposed method than those obtained with other methods. About a point target at a depth of 12 mm, the full widths at half maximum were approximately 0.38 mm (1b), 0.28 mm (2b), and 0.17 mm (3b).

Figures 3(a), 3(b), and 3(c) show B-mode images of the carotid artery without filtering, with the filter using the PSF obtained from a wire placed in water, and with the filter using the proposed method, respectively. In Fig. 3, DRs of B-mode images are controlled.

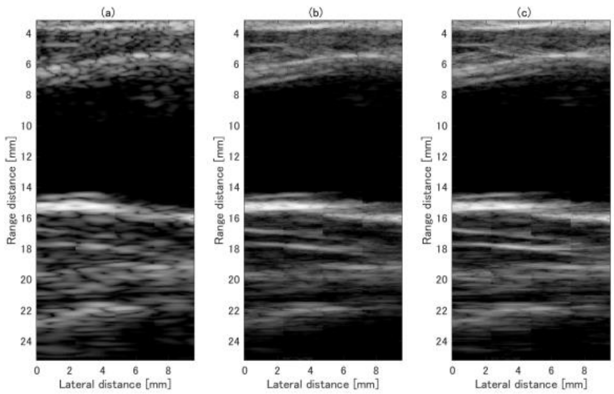

Fig. 3: B-mode images of carotid artery obtained. (a) without filter (DR: 50 dB), (b) with filter using PSF obtained from fine wire placed in water (DR: 130 dB), and (c) with filter using proposed method (DR: 130 dB).

As shown in Fig. 3(c), the echo from the lumen-intima interface of the posterior wall becomes sharp and the penetration in a deep region is improved as compared to Fig. 3(b).

4. Conclusion

In the present study, the transmit-receive response of a diagnostic ultrasound system was estimated using echo signals from an imaging target and used in the proposed filter. From the experimental results, the range spatial resolution was further improved by the proposed method.

References

1. W. Yeoh and C. Zhang: *IEEE Trans. Biomed. Eng.* (2006) 2001.
2. S. Kageyama, H. Hasegawa, and H. Kanai: Jpn. J. Appl. Phys. (2013) 07HF04.
3. H.Hasegawa: Jpn. J. Appl. Phys. (2017) 07JF02
4. H. Hasegawa and H. Kanai: *IEEE Trans. Ultrason, Ferroelectr Freq Contr*. (2008) 2626.