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Study on improvement of spatial resolution in element domain for high-frame-rate ultrasound

高速超音波イメージングにおける素子領域距離分解能向上法の検討

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1. Introduction

The range spatial resolution is an important factor determining the image quality in ultrasonic imaging. The range spatial resolution in ultrasonic imaging depends on the ultrasonic pulse length, which is determined by the mechanical response of the piezoelectric element in an ultrasonic probe.

To improve the range spatial resolution without replacing the transducer elements, signal processing methods have been introduced [1,2]. Such signal processing methods is in general applied to the beamformed ultrasonic signals and work as a filter, which improves the band width of the received ultrasonic signal. To improve the band width of the echo signal, such methods require a reference signal, corresponding to the single ultrasonic pulse. However, the waveform of the received ultrasonic echo varies with depth due to the frequency-dependent attenuation, focusing, nonlinear propagation, etc.

In the present study, a method for improvement of the band width of the ultrasonic echo signals in the element domain to reduce the effect of focusing.

2. Materials and Methods

In the present study, a correlation-based filter was applied to the echo signals received by the individual transducer elements in an ultrasonic probe. By using the filter in the element domain, the change in the waveform of the ultrasonic echo can be reduced because the waveform varies with depth due to focusing [3].

However, in general, a receiving aperture consists of many transducer elements, and the computational cost for application of the filter to many element signals per transmission is significantly high when the conventional line-by-line transmit-receive sequence is used. Therefore, filtering in the element domain is not preferable for conventional linear scanning.

On the other hand, in high-frame-rate imaging using unfocused transmit beams, such as plane wave, an ultrasonic image can be obtained with several transmission and, thus, filtering in the element domain is feasible.

Figure 1 shows a block diagram explaining the proposed method. In the proposed method, the beamforming procedure separated into two ways to create the range and lateral spatial resolutions. The lateral resolution was created by conventional band-pass filtering to the element signals and conventional delay-and-sum (DAS) beamforming. To improve the range spatial resolution, a correlation-based filter was applied to the element signals before performing DAS beamforming. An ultrasonic echo from a 15-μm stainless wire was used as a reference signal in the correlation-based filtering. Although the previously proposed methods require the frequency analysis of the received echo signal and the processing of the complex signal, the proposed method uses only the real number analysis.

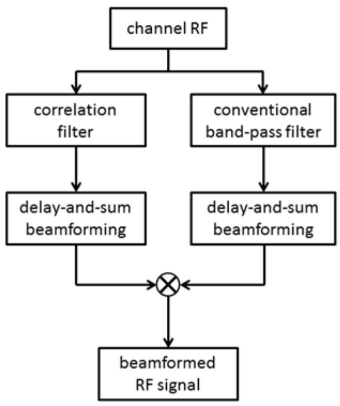

Fig. 1 Block diagram of the proposed method.

The transmit-receive sequence is described in [4]. In the present study, the number of emissions of plane waves for creation of one image frame was set at 4, and each plane wave was emitted using 96 transducer element. In each transmission, 24 focused receiving beams were created at intervals of 0.1 mm, and the aperture used to create one focused receiving beam consisted of M = 72 elements. Consequently, one image frame consisted of 24 × 4 = 96 focused receiving beams was obtained by four times emissions of plane waves.

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2. Experimental Results

Figures 2(a) and 2(b) show B-mode images of a 15-µm stainless wire placed in a water tank obtained by the DAS beamformer without and with the proposed element-domain correlation filtering.

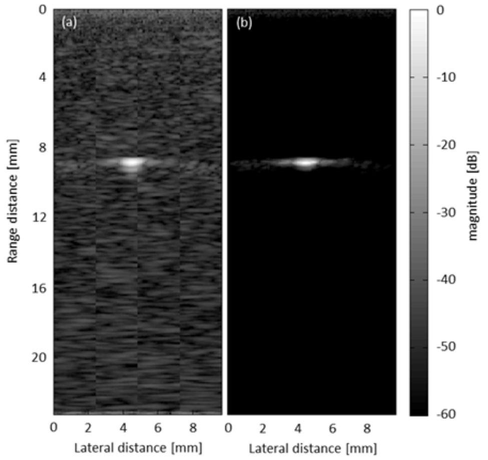


Fig. 2: B-mode images of a 15-µm stainless wire placed in a water tank obtained with DAS beamformer without (a) and with (b) the proposed element-domain correlation filtering.

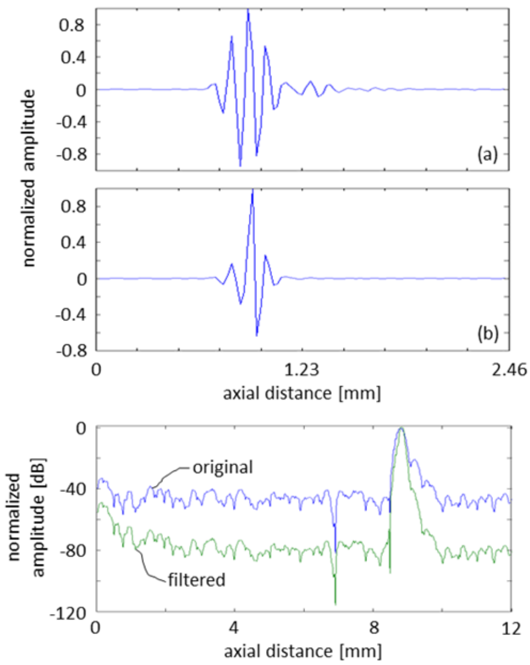


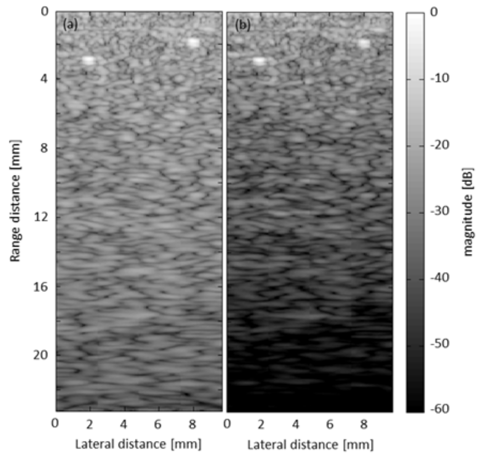
Fig. 3: (a) Original RF signal received by a transducer element. (b) RF signal received filtered by the proposed correlation-based filter. (c) Envelopes of the beamformed RF signals obtained without (original) and with (filtered) the proposed correlation-based filter.

Figure 3(a) shows an example of an ultrasonic RF echo received by a transducer element. The waveform in Fig. 3(a) was used as the reference signal in the proposed correlation-based filtering. By applying the proposed correlation-based filter to the echo signal shown in Fig. 3(a), the pulse length was shortened significantly, as shown in Fig. 3(b).

By shortening the pulse length, the range spatial resolution was improved, as shown in Fig. 2(b). Figure 3(c) shows the axial amplitude profiles at the peaks in Figs. 2(a) and 2(b). The range spatial resolution, which was defined as the width at half maximum of the axial amplitude profile, was improved from 0.25 mm to 0.16 mm using the proposed correlation-based filtering applied in the element domain. Also, noises in Fig. 2(a) could be suppressed as shown in Fig. 2(b).

Figures 4(a) and 4(b) show B-mode images of a string phantom obtained by the DAS beamformer without and with the proposed element-domain correlation filtering. Even in the measurement of a target, which is different from that used to obtain the reference signal, the range spatial resolution was improved from 0.26 mm to 0.21 mm.

Fig. 4: B-mode images of string phantom obtained



with DAS beamformer without (a) and with (b) the proposed element-domain correlation filtering.

6. Conclusion

In the present study, a correlation-based filter was proposed and applied to the ultrasonic echoes received by individual transducer elements. Through the phantom experiments, the proposed method has shown to improve the range spatial resolution.

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