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Basic study on differentiation of reflection and scattering components by synthetic aperture method using spherically diverging transmit beams
球面拡散波を用いた開口合成法による反射・散乱成分との分別に関する基礎的研究

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1. Introduction

Endothelial cells on the internal surface of the arterial wall are reportedly damaged in the early-stage atherosclerosis. Due to the injury of endothelial cells, the luminal surface of the arterial wall is believed to become rougher. This would increase scattering at the expense of semi-specular reflection when ultrasound is irradiated. Therefore, differentiation between reflected and scattered components in an ultrasonic echo from the arterial wall holds potential of diagnostic value when such roughening occurs. In previous work by our group, the differentiation of the scattered and the reflected components in the echo signal was examined by a linear scanning method using far-focused transmit beams. In this preliminary investigation, the spatial resolution of the image generated using only the backscattering component was improved and a given interface was imaged with less speckles [1]. In the present study, we have attempted to differentiate the reflection and scattering components by synthetic aperture imaging using spherically diverging waves and compared the images generated for both components. In addition, we have studied the calculation of the receive propagation distance for a plane sound source assuming that there is a horizontal reflecting surface at the target point.

2. Principle

2.1. Synthetic aperture method

A synthetic aperture method using a spherically diverging transmit beam was used. To form a wavefront that diverges in a spherical shape from a virtual sound source behind the array placed at (x_f, z_f), it is necessary to increase the delay time of the emitted pulses as the distance from the aperture center increases [2]. The transmission propagation distance r_t from the center of the aperture to the target point (x_t, z_t) is obtained by Eq. (1).

$$r_t = \sqrt{\left(x_t - x_f\right)^2 + \left(z_t - z_f\right)^2} - |z_f|. \qquad (1)$$

Similarly, the receiving propagation distance r_i from the target point to i-th element in the aperture at $(x_t, 0)$ is obtained by

$$r_i = \sqrt{(x_i - x_t)^2 + {z_t}^2}. \qquad (2)$$

2.2. Method for differentiation of reflection and scattering components

In the present study, we have developed a method of differentiation the reflection and scattering components of ultrasonic echoes by using spherically diverging transmit beam. In the case of the target point in **Fig. 1**, the ultrasonic beam is insonified from the $-\varphi$ direction and reflected in the φ direction. We considered the arrival point of the reflection component as $(x_r, 0)$ and that of the backscattering component as $(x_b, 0)$.

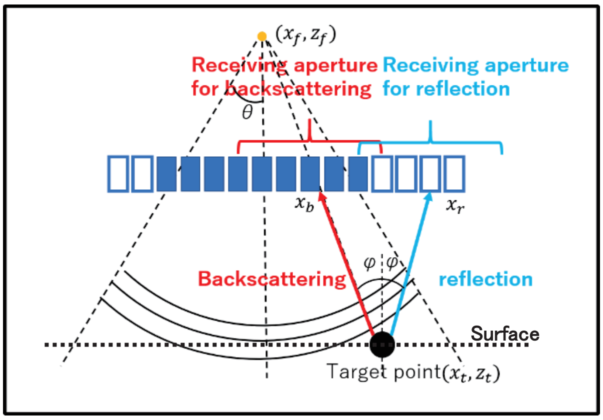

Fig. 1 Illustration of method for differentiation of reflection and backscattering components.

2.3. Receive propagation distance for plane sound source

Conventionally, the receive propagation distance was calculated by assuming the reflection originated from a point sound source. However, as shown in **Fig. 2**, it is necessary to calculate the receive propagation distance as a reflection from a flat surface. In the present study, a horizontal reflection surface at the target point was assumed. In such a case, the receive propagation distance r_i is obtained by Eq. (3).

$$r_i = \sqrt{\left(x_i - x_f\right)^2 + (2z_t + |z_f|)^2} - \sqrt{\left(x_t - x_f\right)^2 + (z_t + |z_f|)^2}. \qquad (3)$$

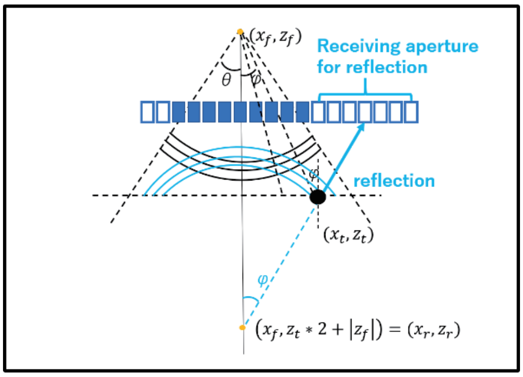

Fig. 2 Illustration of calculation of receive propagation distance for plane sound source.

2.4. Experimental setup

In the experiments, a linear array transducers with element pitches of 0.1 mm and 0.2 mm were used. The center frequency of the transducers was 7 MHz. Ultrasound echoes received by individual transducer elements were sampled at a sampling frequency of 62.5 MHz. The sound velocity was assumed to be 1482 m/s when doing the beamforming. The object to be scanned was a phantom composed of a string with a diameter of 0.03 mm and rubber plate of a thickness of 14 mm. In synthetic aperture imaging, a virtual point source was located at -40 mm behind the probe surface. The full width at half maximum of an echo from the string was used for evaluation of spatial resolution.

3. Results and Discussion

Fig. 3 shows B-mode images in a 10×10 mm region. **Fig. 3**(a)-(f) shows B-mode images obtained by conventional synthetic aperture imaging, as well as the reflection emphasized image, and backscattering emphasized image. The lateral full width at half maximum of the echo from the wire obtained from scattering component with element pitches of 0.2 mm was 0.35 mm showed the best lateral resolution. Using reflection components [**Figs. 3**(b) and **3**(e)], the interface was imaged as more flat.

Fig. 4 shows images of 10×10-mm regions with element pitches of 0.1 mm. **Fig. 4**(a) and **4**(b) shows B-mode images obtained by assuming a point sound source and plane sound source, respectively. The lateral full width at half maximum of the echo from the wire using the reflection component obtained with element pitches of 0.1 mm and assumption of a plane sound source was 0.91 mm, showing a degradation of the lateral resolution. On the other hand, visibility of the interface in an image obtained with assumption of a plane sound source was improved.

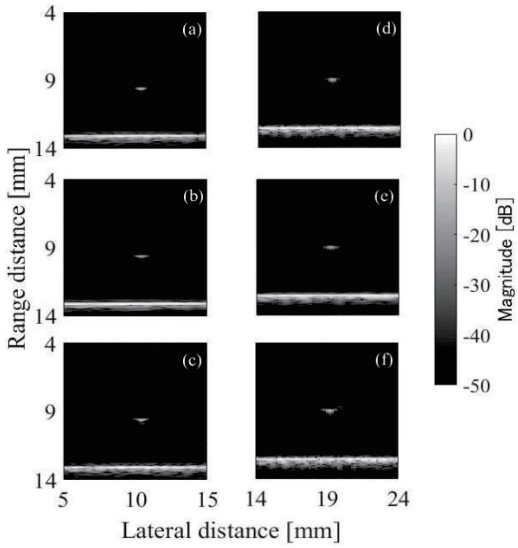

Fig. 3 B-mode images obtained with element pitch of 0.1 mm using (a) synthetic apertur and showing (b) reflection and (c) scattering emphasized images. B-mode images obtained with element pitch of 0.2 mm using (d) synthetic aperture, and showing (e) reflection and (f) scattering emphasized images.

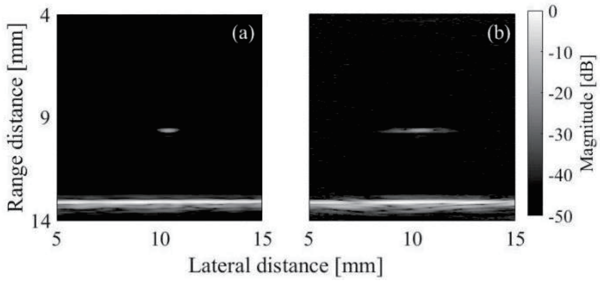

Fig. 4 B-mode images obtained with element pitch of 0.1 mm by assuming (a) a point sound source and (b) a plane sound source.

4. Conclusions

In the present study, we examined a method for extracting reflection and scattering components from ultrasonic echoes. Using the proposed method, an interface could be imaged with less speckles using reflection components, and a scatterer was visualized with better lateral resolution using scattering components.

References

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