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Investigation on improvement of spatial resolution of ultrasound images by considering propagation delay time of transmitted wave

送信波の伝搬遅延時間の考慮による超音波画像の空間分解能向上の検討

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1. Introduction

In order to improve the frame rate of echocardiography, synthetic aperture imaging using a focused ultrasound beam was investigated in this study. Unfocused ultrasound beams such as spherical waves are commonly used in synthetic aperture imaging to illuminate a wide area. However, when the scanning target is located at a deep position, an unfocused beam has a problem that the sound pressure is not as high as a focused beam. Therefore, in the present study, a synthetic aperture method using a focused transmit beam was investigated.

In the present study, we investigated the possibility of improving the imaging accuracy in a sector format by synthetic aperture imaging with focused ultrasound beams by creating a database of propagation delay times of the transmitted waves in advance by computer simulation and referring to it when calculating the forward propagation delays.

2. Experimental Methods

In order to create a database of propagation delay times of transmitted waves, we first simulated a focused wave transmission from a phased-array probe with the parameters shown in **Table I** using Field II [1,2] and calculated the sound pressure at each point of interest in an imaging field.

The time t_0 at which the amplitude of the transmitted wave is maximum at each point of interest was calculated, and the delay time from the start of transmission was stored in a database. In the present study, if the amplitude of the transmitted wave was more than 1% of the maximum sound pressure observed in the entire imaging field, the propagation delay was calculated assuming that the point has been illuminated by the transmitted wave.

In the experiment, the transmitted beam was steered within ±22.5° at angle intervals of 2.25° to transmit ultrasonic waves in 21 directions, and a database of propagation delay times for all the steering angles was created by the above procedure.

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Table I Parameters in simulation

Center frequency	3 MHz
Sampling frequency	31.25 MHz
Speed of sound	1540 m/s
Focal length	100 mm
Number of elements	80

When the center of the aperture is the origin, the forward propagation distance r_t from the origin to a point of interest can be expressed by equation (1).

$$r_t = \sqrt{x_t^2 + z_t^2} \tag{1}$$

where x_t and z_t are the coordinates of the point of interest.

A B-mode image obtained by synthetic aperture imaging are the sum of low-resolution images obtained from different transmissions. However, the forward propagation distance calculated by equation (1) is based on the assumption that the transmitted wave is perfectly spherical, and there may be a deviation from the assumption when a spherical wave is generated using multiple elements. Such a deviation would degrade the spatial resolution of the B-mode image. In the present study, we utilized the database of propagation delay times in the calculation of the forward propagation distance to obtain a more accurate estimation of the forward propagation distance.

Also, two methods of compounding low-resolution images were examined: incoherent compound for blood flow imaging and coherent compound for B-mode imaging of the heart wall.

A synthetic aperture beamforming technique based on the delay-and-sum method was applied to the ultrasound RF signals obtained from a phantom containing a cyst and a string to obtain low-resolution images. The spatial resolutions obtained using Eq. (1) and the database were compared by evaluating a full width at half maximum (FWHM) of an echo from a string target.

3. Results

The forward propagation delay is determined by referring to the database of propagation delay times of transmitted waves, and the B-mode image created by coherent compound is shown in **Fig. 1**.

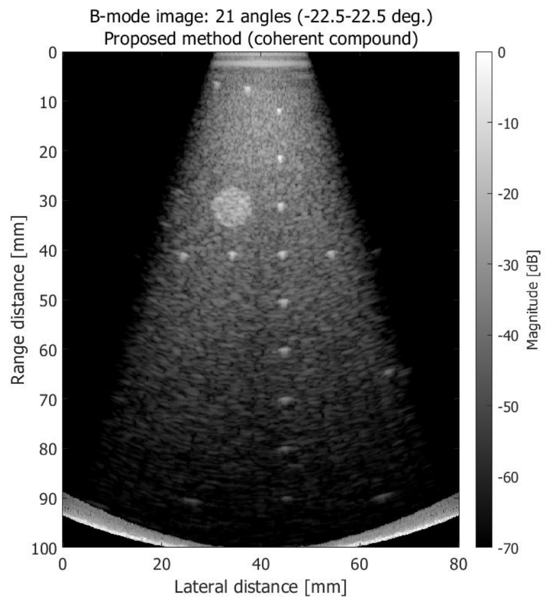

Fig. 1 B-mode image by proposed method (coherent compound)

Figures 2 and **3** show the lateral and axial echo amplitude profiles obtained at the peak of the echo from the string located at a depth of 12 mm. **Table 2** shows the FWHMs in the lateral and axial directions calculated from the B-mode image produced by coherent compound, and **Table 3** shows the FWHMs calculated from the B-mode image produced by incoherent compound.

From **Table 2**, it can be seen that the spatial resolution of the b-mode image created by coherent compound is improved by applying the database of the propagation delays of the transmitted waves to the beamforming process. Similarly, **Table 3** shows that the spatial resolution of the B-mode image created by incoherent compound is improved by applying the database of the propagation delays of the transmitted waves to the beamforming process.

Table 2 Lateral and axial FWHMs obtained with coherent compound

	Conventional	Proposed
Lateral	0.40 mm	0.20 mm
Axial	0.45 mm	0.40 mm

Table 3 Lateral and axial FWHMs obtained with incoherent compound

	Conventional	Proposed
Lateral	1.20 mm	0.60 mm
Axial	0.50 mm	0.45 mm

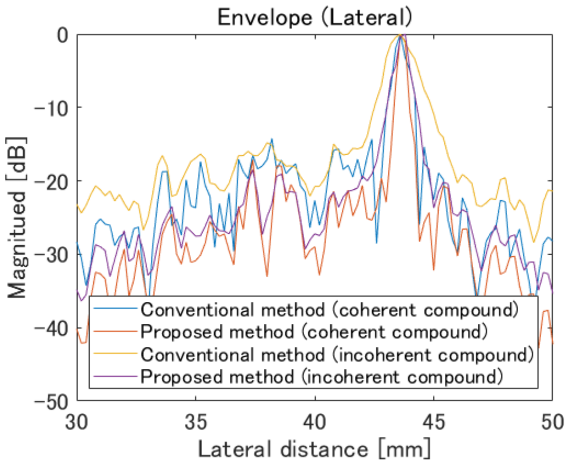

Fig. 2 Lateral amplitude profiles of echo from string located at a depth of 12 mm shown in Fig. 1. (blue) Conventional method with coherent compound. (red) Proposed method with coherent compound. (yellow) Conventional method with incoherent compound. (purple) Proposed method with incoherent compound.

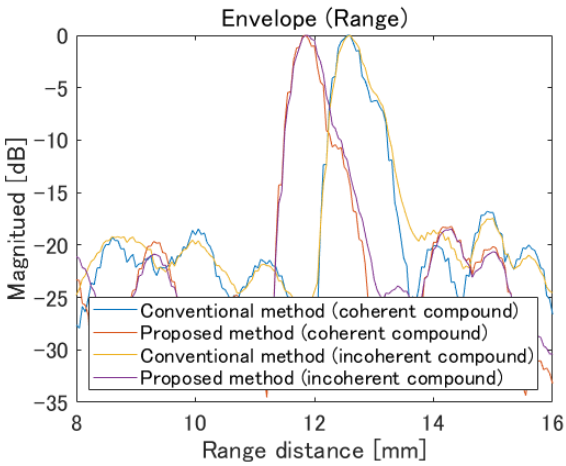

Fig. 3 Axial amplitude profiles of echo from string located at a depth of 12 mm shown in Fig. 1. (blue) Conventional method with coherent compound. (red) Proposed method with coherent compound. (yellow) Conventional method with incoherent compound. (purple) Proposed method with incoherent compound.

4. Conclusion

In the present study, we investigated whether the spatial resolution of a B-mode image can be improved by taking propagation delay times of transmitted waves into account by creating the database of the delay times in advance by numerical simulation. The FWHMs show that the spatial resolution of the B-mode image can be improved by considering the propagation delay time obtained from the simulation, regardless of coherent and incoherent compound in synthetic aperture image formation.

References

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2. J. A. Jensen and N. B. Svendsen: IEEE Trans. Ultrason. Freq. Control **39** (1992) 262.