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Synthetic aperture imaging with numerical simulation of propagation delay time of transmitted wave

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1. Introduction

To achieve higher frame rates in echocardiography, synthetic aperture imaging with a focused ultrasound beam was investigated in this study. Unfocused ultrasound beams such as spherical waves and plane waves are commonly used in synthetic aperture imaging. However, when scanning a deeply located object, image quality would be degraded because sound pressure of an unfocused beam is not as high as a focused beam. Therefore, in this study, a synthetic aperture method using a focused transmit beam was investigated.

In synthetic aperture imaging with focused ultrasound beams, we proposed the method of improving the imaging accuracy in a sector format by creating a database of propagation delay times of the transmitted waves in advance through computer simulation and referring to them when calculating the forward propagation delays in receive beamforming [1]. So far, we have used the Tukey function for transmission apodization in this method. However, a B-mode image created by this method using the Tukey apodization have a problem with discontinuous stripes pattern. In this study, we used the Hanning function for transmission apodization to solve this problem.

2. Methods

To create a database of propagation delay times of transmitted waves, we first simulated a focused wave transmission from a phased-array probe using Field II simulation software and calculated the sound pressure at each point of interest in an imaging field [2,3]. The parameters used in the simulations are listed in **Table I**.

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

Then, the time t_0 at which the amplitude of the transmitted wave becomes maximum was determined at each point of interest, and the delay time from the time of transmission was stored in the database. So far, we had calculated the propagation delay by assuming that the point has been illuminated by the transmitted wave if the amplitude of the transmitted wave was more than 1% of the maximum sound pressure observed over the entire imaging field, but this threshold could include sidelobe signals. Therefore, in this study, the threshold to judge that a point of interest was illuminated by transmitted waves was changed to 10% of the maximum sound pressure observed over the entire imaging field.

In the experiment, ultrasonic waves are transmitted in 21 directions by steering the transmission beam within ±22.5° at an angular interval of 2.25°. Therefore, a database containing propagation delay times for all steering angles, 21 in total, was created using the procedure described above.

In the present study, the simulation of ultrasonic echo signals from a rotating phantom was performed using the Field II simulation software [2,3]. The size of the cylindrical phantom was set to 25 mm in radius and 20 mm in thickness, and 2.55 / mm^3 in scatterer density, and rotated at a constant speed of 50 mm/s at the outermost surface of the phantom. The bias error (BE) and the root mean square error (RMSE) were respectively estimated as

$$BE = \mathrm{E}_{x_t,z_t \in R}[v_{est}(x_t,z_t) - v_{true}(x_t,z_t)], \quad (1)$$

$$RMSE = \sqrt{\mathrm{E}_{x_t,z_t \in R}[(v_{est}(x_t,z_t) - v_{true}(x_t,z_t))^2]}, \quad (2)$$

where $v_{est}(x_t,z_t)$ and $v_{true}(x_t,z_t)$ are the estimated and true velocities at point of interest (x_t,z_t), respectively, $\mathrm{E}[\cdot]$ denotes expectation, and R is the region where the phantom exists.

3. Results

Figs 1(a) and **1(b)** show the lateral sound pressure distribution at a range distance of 90 mm obtained with the Tukey and Hanning functions, respectively. **Figs 2(a)** and **2(b)** show the transmission distances at a range distance of 90 mm calculated by referring to the delay time database created by simulating with the Tukey and Hanning functions, respectively. From Fig. 1(a), we can see abrupt changes in sound pressure around 35 mm and

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45 mm, and from Fig. 2(a), we can see a similar change in the transmission distance. From Figs. 1(b) and 2(b), it can be seen that such abrupt changes in sound pressure and transmission distance are no longer observed when the Tukey apodization is changed to the Haninng one. Therefore, the abrupt changes in sound pressure and transmission distance are considered to be the cause of the discontinuous stripe pattern.

Figs 3 and **4** show the B-mode images generated by the proposed method with Tukey and Hanning apodizations, respectively. The BE and RMSE calculated from the estimated and true velocities were evaluated with respect to each method and are shown in **Table II**. From Figs. 3 and 4, it can be seen that the discontinuity stripe pattern, which is shown in the image obtained with Tukey apodization, was reduced by changing the transmission apodization to the Hanning function. In addition, from Table II**,** it can be seen that the accuracy of velocity estimation is also improved by applying the database of propagation delays of the transmitted wave using the Hanning function to the beamforming process.

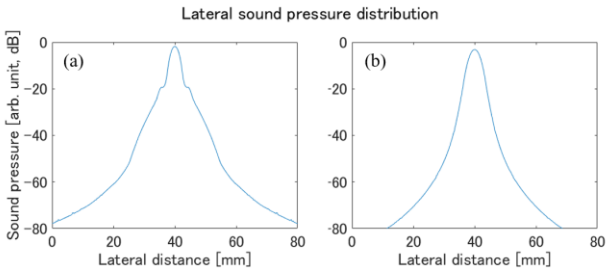

Fig. 1 Sound pressure distributions at a range distance of 90 mm when simulated with (a) Tukey and (b) Hanning apodizations.

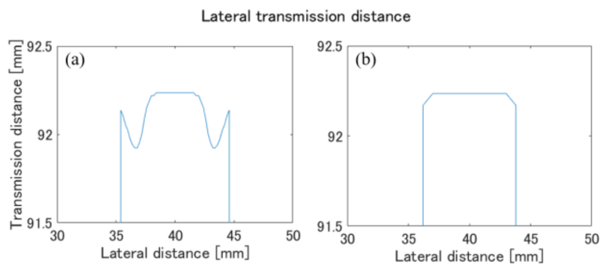

Fig. 2 Transmission distance distributions at a range distance of 90 mm calculated by referring to the delay time database created by simulations with (a) Tukey and (b) Hanning apodizations.

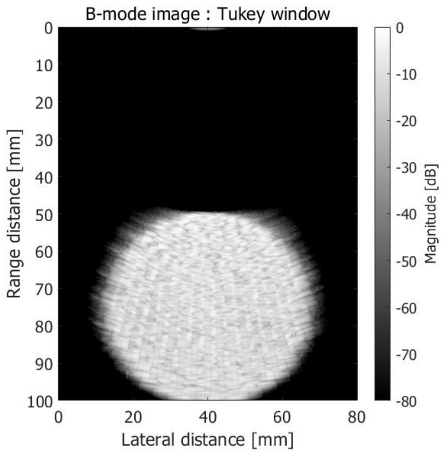

Fig. 3 B-mode image obtained by proposed method with Tukey apodization.

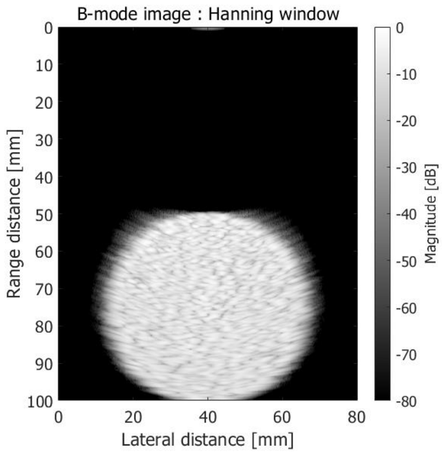

Fig. 4 B-mode image obtained by proposed method with Hanning apodization.

Table II BE and RMSE in estimated velocities.

	Tukey	Hanning
BE	-0.093 mm/s	-0.006 mm/s
RMSE	±10.108 mm/s	±9.098 mm/s

4. Conclusion

In this study, we investigated the source of the discontinuous stripe patterns in B-mode images, such stripe patterns could be reduced by changing the transmission apodization from the Tukey function to the Hanning function in the synthetic aperture imaging method with the transmission delay database obtained by numerical simulation of transmitted waves. Furthermore, it was confirmed that the accuracy in velocity estimation was also improved.

References

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