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Improvement of spatial resolution in low-frequency ultrasound imaging by using pulse compressed parametric sound

パルス圧縮パラメトリック音源による
低周波超音波イメージングの分解能改善

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1. Introduction

Acoustic imaging using ultrasound at several hundred kHz has been considerable attention in recent years[1], since ultrasounds at several MHz for ultrasonography show excellent spatial resolutions, although the penetration depth is limited because of the acoustic energy attenuation due to the viscosity of medium. In order to realize low-frequency ultrasound imaging, we have applied the pulse compression (PC) technique to the low-frequency parametric acoustic array, which forms a sharp directive sound beam at low-frequency and is generated by the nonlinear interaction of high intense ultrasounds [2,3].

In this study, we numerically simulate the low-frequency parametric sound imaging applied by the PC, and estimate the range resolution of that.

2. Method

Ultrasound imaging for multi targets in water was simulated to estimate the range resolution. In order to improve the directivity and range resolution of low-frequency ultrasound, we applied the PC to the low-frequency parametric ultrasound.

Linearly aligned five rigid cylinders with 2-mm diameter were placed in water as targets shown in **Fig. 1**. To simplify the simulation, we assumed the model to be uniform along the longitudinal direction of the cylinders. The details of the numerical simulation for nonlinear ultrasound propagation is described in the previous paper[4].

A transmitter with 25.4 mm in width was placed at the range distance of 0 mm in Fig. 1. A receiver with 8.8 mm in width received only parametric sound echoes at the range distance of 0 mm and every 1 mm in the lateral distance of ±30 mm. A B-mode image based on the echo signals with the PC was produced as an ultrasound image.

Modulated ultrasounds at the center frequency of 2.8 MHz were radiated from the transmitter to generate linear chirp modulated parametric sound of sweep frequency from 100 to 500 kHz and sweep duration time of 33.3 μs. The PC was performed with the processing of cross-correlation between an echo signal and a reference signal, which has uniform amplitude at sweep frequency from 100 to 500 kHz in during sweep time of 33.3 μs[2–4].

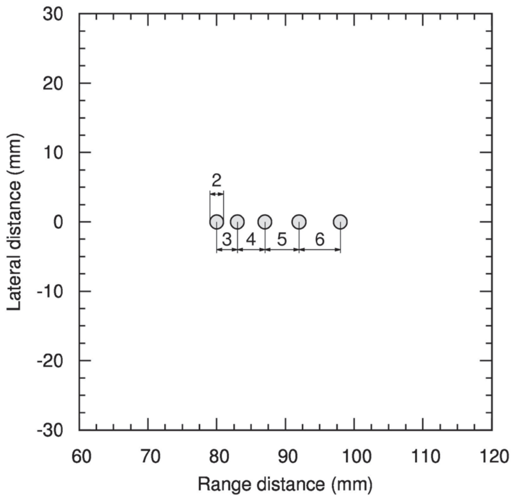

Fig. 1 Simulation model. Sound sources are located at the range distance of 0 mm.

3. Results and Discussion

Low-frequency ultrasound images obtained by parametric sound without and with the PC are shown in **Fig. 2** (a) and (b), respectively. Both images are produced by the normalized amplitude of echo signals. These results show that the image with the PC indicates images of five targets concentrated at correct range distances, although the image without the PC spread to the range direction. However, the image with the PC spreads to the lateral direction.

The minimum gap distance of targets is 1 mm, and these target images are separated in Fig. 2 (b). The theoretical range resolution of PC is determined by the pulse width, which corresponds to the reciprocal value of the chirp bandwidth, and

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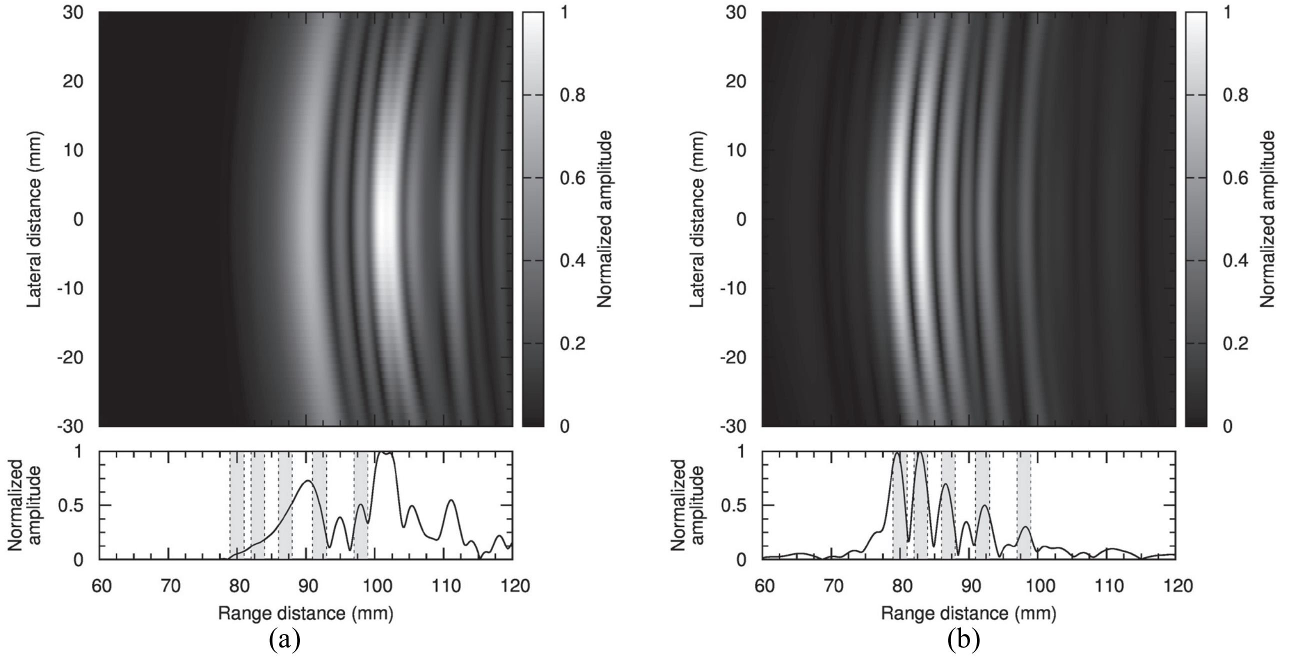

Fig. 1 Ultrasonic images obtained by low-frequency parametric sound (a) with and (b) without pulse compression. Top and bottom figures are B-mode and A-mode images at lateral distance of 0 mm, respectively. Gray zones in the bottom figures indicate the ideal target positions.

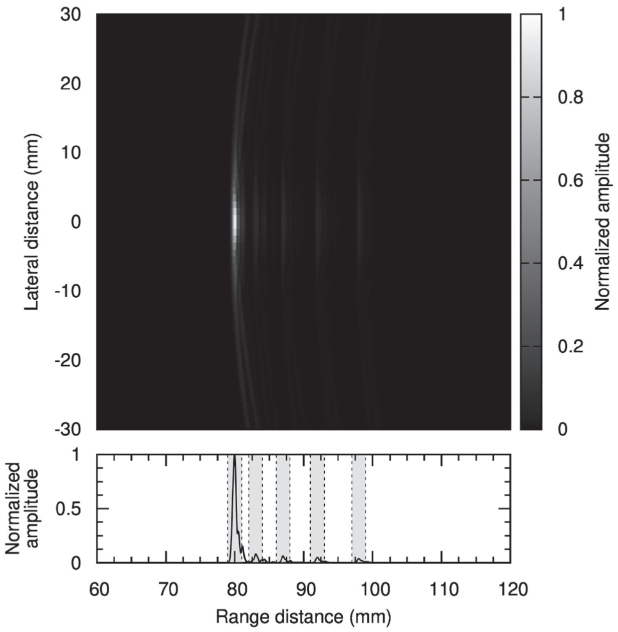

Fig. 2 Ultrasonic image obtained by high-frequency ultrasound short pulse.

is about 2 mm in this simulation model. This result implies that the ideal performance of PC is obtained for low-frequency parametric sound imaging.

For a reference, an ultrasonic image obtained by high-frequency short pulse for the same targets is shown in **Fig. 3**. The transmitted ultrasound was three-cycle signal of Gaussian envelope at a center frequency of 2.8 MHz. The sizes of image along the range and lateral directions are smaller than that obtained by low-frequency ultrasound.

It is noted that the high-frequency ultrasound does not depict images of behind targets located behind the most front target. A possible interpretation of this result is that the diffraction of ultrasound at high frequency is weaker than that at low frequency.

4. Conclusions

In order to realize low-frequency ultrasound imaging, we estimated the range resolution of low-frequency parametric sound image applied by PC using numerical simulations. The resolution of simulated image satisfies the theoretical value. In addition, the results suggest that the low-frequency image by the pulse compressed low-frequency parametric sound can image a target existed in the shadow of other targets.

Acknowledgement

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