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Range Stacked Apodization on Synthetic Aperture Array Signal Processing

配列開口合成処理に基づく空間周波数領域での距離可変アポダイゼーションの検討

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1. Introduction

Synthetic aperture (SA) processing using an array transducer is a signal processing technique essential for reconstructing high-resolution images at a high frame rate (a few thousand frames per second) from two-dimensional echo data collected by each element in parallel. This technique has been applied to ultrasonic diagnosis, in which advanced technologies used in biopsy, such as elastography, have recently contributed to medicine[1]. In the reconstructed data, however, artifacts are generated outside the region of measurement at a distance away from the center of the array transducer because of the azimuthal asymmetry of echo data collected in parallel through a finite aperture.

Particularly in the high-accuracy estimation of subwavelength-order local displacement vectors from random speckle echo data throughout soft tissue specimens, local phase characteristics from different sound sources must be stable within the measurement space[2-3].

Previously, we reported that apodization is a useful technique for restricting unnecessary spatial frequency spectrum in the azimuthal direction of echo signals and for stabilizing the local phase characteristics of point spread functions (PSFs) in the reconstructed measurement region[4-5]. In concrete terms, practical-level accuracy in the estimation of the displacement vector was achieved by combining distance-dependent apodization in the spatial frequency domain with a range-stacking algorithm of SA radar. In this study, we report an algorithm based on systematic design for a finite-array SA reconstruction system in the two-dimensional frequency domain with time and azimuth axes.

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PSF of finite-array SA reconstruction system

A simulation was carried out using an array transducer to evaluate the reconstruction performance of the finite-array SA reconstruction system. In the simulation, 256 elements with a central frequency of 3 MHz and a band frequency of 2 MHz were arranged at an element pitch of 0.25 mm. A virtual point sound source was established at a position (8 mm, 16 mm) in the (x,y) coordinate system, the origin of which was at the center of the array transducer. Thus, two-dimensional echo signals were received by each element in parallel. As shown in Fig.1, nine point targets were arranged at regular intervals.

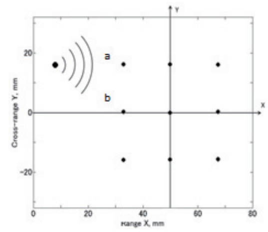

Fig.1 Simulation model of finite-array SA reconstruction system.

To clearly understand the spatial characteristics of the finite-array SA reconstruction system, typical two-dimensional phase distributions of PSFs obtained by reconstructing radio frequency (RF) echo frames (RF-PSFs) at target positions a and b, located at a distance from the array transducer, are shown in Figs.2a and 2b, respectively.

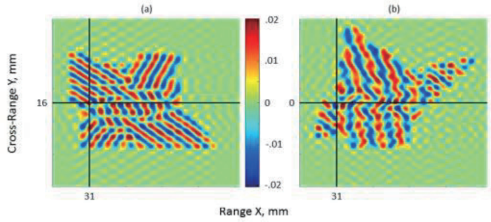

Fig.2 2D phase distribution of RF-PSFs at a position of a and b.

Such complicated spatial distributions at the phase level may cause serious errors in the estimation of local phase difference. These errors are closely related to the azimuthal asymmetry of the two-dimensional echo data, which is produced by the point targets that shift in the azimuthal direction when two-dimensional hyperbolic echo data from the point targets are collected through the finite aperture. Figures 3a and 3b show the two-dimensional echo data used for reconstruction in Figs. 2a and 2b, respectively.

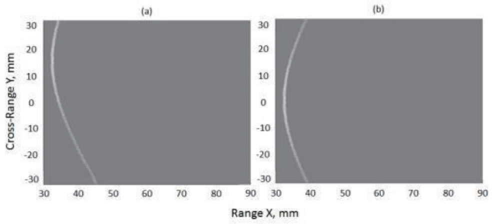

Fig3 2D echo at position of a and b.

Although the two-dimensional echo data in Fig. 3b is symmetric, the reconstructed image in Fig. 2b has a complicated phase distribution. Thus, errors are caused not only by the asymmetry of the two-dimensional echo data but also by unnecessary components included in the two-dimensional echo data. Therefore, the unnecessary components must be suppressed. When the unnecessary components are restricted in the time domain, however, necessary components in any overlapped echo frames are also restricted. Hence, apodization must be carried out in the two-dimensional frequency domain.

3. Apodization in spatial frequency domain

Apodization is required to achieve a high-accuracy phase distribution in the direction of irradiation from a sound source for the PSFs of the SA reconstruction system. Conventionally, apodization was introduced in the two-dimensional spatial frequency domain (kx,ky) where SA processing is sequentially performed within small range-stacking segments. In this study, we examined apodization in the two-dimensional frequency domain (f,ku) for use in the high-accuracy detection of small displacements. Two-dimensional echo signals must be divided into necessary and unnecessary components to achieve appropriate apodization. The analysis indicates that the part becoming linear in the two-dimensional hyperbolic echo data corresponds to the high-frequency components distributed in the positive and negative directions of ku in the fan-shaped spectram in the two-dimensional frequency domain, as shown in Figs. 4a and 4b.

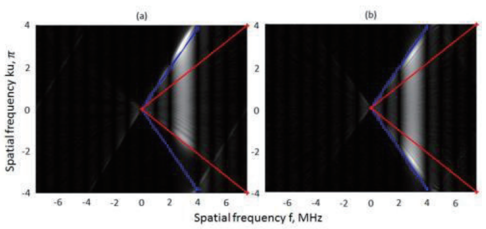

Fig4 2D frequency spectram of 2D echo a at position of a and b.

Therefore, restricting the high-frequency components allows the reconstructed PSFs to have a sinusoidal phase distribution in the direction of the irradiation from the sound source. When a raised-cosine filter, which changes the effective bandwidth depending on the f-direction, was used to restrict the high-frequency components, appropriate apodization was achieved. Fig.5a and 5b show the apodized spectrum.

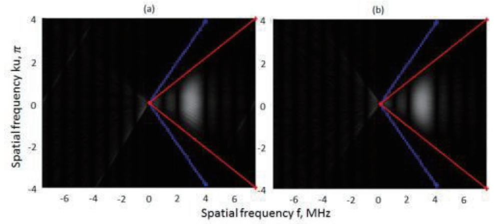

Fig5 2D frequency spectrum apodized of 2D echo position of a and b

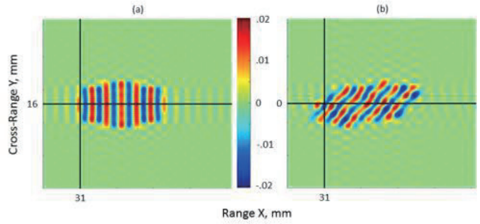

Fig6 Directional phase variations of apodized RF-PSFs at a position of a and b.

In these figures, the unnecessary components are appropriately restricted. As a result, sinusoidal phase distributions in the direction of irradiation from the virtual point sound source were obtained at targets A and B by the apodization of the finite-array SA reconstruction system, as shown in Figs. 6a and 6b, respectively.

4. Conclusions

Apodization in the spatial frequency domain for finite-array SA processing was found effective for the algorithm to detect small displacements. We will further optimize the finite-array SA reconstruction system in future work.

References

1. J. Bercoff, M. Tanter, M. Muller, and M. Fink: IEEE Trans. UFFC, 51(11), 1523-1536 (2004).
2. Y. Minochi, S. Yagi, T. Nishiyama: JJAP, 43(B5), 3103–3106 (2004).
3. S. Yagi, R. Yokoyama, K. Tamura, and M. Sato: JJAP, 50, 07HF06-1-3 (2011)
4. D. Sugeno, S. Yagi, K. Tamura,and M. Sato: USE vol.35 pp.509-510(2014)
5. M. Katsuyama, S. Yagi, D. Sugeno, K. Tamura,and M. Sato: Acoust. Sci. Tech. 36(3), 2015.