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Fourier Beamforming with no approximate processing for virtual source
仮想音源を用いた補間近似処理を要さないフーリエビームフォーミング

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1. Introduction

An ultrasonic Fourier beamforming is performed to achieve a higher speed processing than a precise phase-rotation delay-and-summation beamforming. To cope with sever artifacts generated by performing approximate interpolations of angular spectra by other groups, the author has been developing several approaches without the approximations; and the feasibility of the approaches have been verified through 3D or 2D imaging of wire or agar phantoms, etc [1]. One of our target was to make it possible to perform an arbitrary-shape-arrayed aperture Fourier beamforming in an arbitrary coordinate system without any approximate interpolations, for instance, direct generations of rf-echo data in a Cartesian coordinate system when using a convex or sector probe, or using a virtual point source set behind a linear-array-type probe, etc. [2,3]. The approach performs the Jacobi operation for the Fourier transform of received echo data to yield the angular spectra directly in a Fourier domain corresponding to the target coordinate system. This report focuses on the use of a virtual source.

2. Method

With respect to reception 2-dimensional (2D) echo signals rf(r,θ) expressed in a discrete polar coordinate system (r,θ), the angular spectra RF(X,Y) expressed for a discrete Cartesian coordinate system (x,y) can be calculated by implementing the Fourier transform with a Jacobi operation onto rf(r,θ) as follows:

$$\mathrm{RF}(X,Y) = \iint_{x,y} \mathrm{rf}(r,\theta)\exp(-j2\pi)(xX+yY)\,dxdy$$
$$= \iint_{r,\theta} \mathrm{rf}(r,\theta)|r|\exp(-j2\pi)r(X\cos\theta+Y\sin\theta)\,drd\theta, \quad (1)$$

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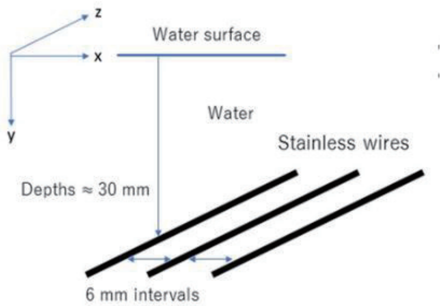

Fig. 1　Wire phantom.

where |r| is Jacobian with respect to

$$x = r\cos\theta \text{ and } y = r\sin\theta. \quad (2)$$

Then, the Fourier-beamformed echo signals can be directly obtained in a discrete Cartesian coordinate system (x,y) by implementing the inverse fast Fourier transform (IFFT) onto RF(X,Y).

When using a point virtual source set behind a linear-array-type probe, delays are set for reception signals rf(x,y) in the Fourier domain by implementing phase rotations to yield rf(r,θ), i.e., virtually generated reception signals using a virtual circular-array-type probe. Such delays can also be implemented when performing the Fourier transform of Eq. (1).

When using a spherical-array-type probe indeed or virtually, 3-dimensional (3D) echo signals rf(x,y,z) expressed in a discrete coordinate system (x,y,z) can be directly calculated with respect to reception 3D echo signals rf(r, θ,φ) similarly.

3. Phantom experiments

The new approach was verified experimentally for wire phantom data used in [1-3]. Three stainless wires (0.23 mm-dia.) immersed at about 30 mm depth (y) in a water with 6 mm pitch in x-direction and running in z-direction (**Fig. 1**)

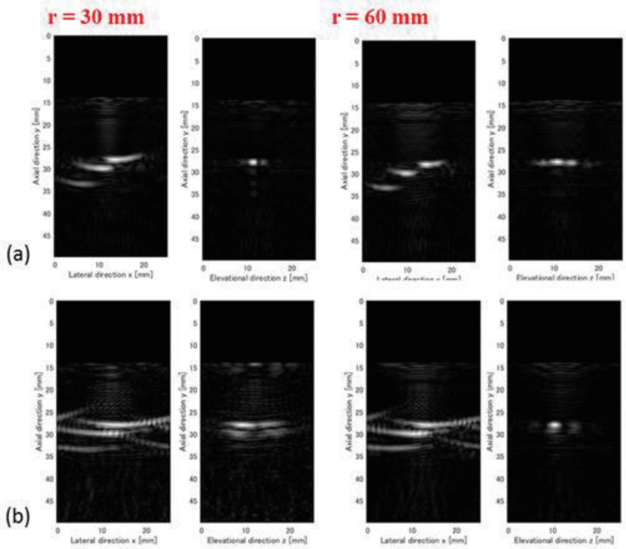

Fig. 2 Echo images obtained using virtual spherically 2D-arrayed aperture probes with 2 different curvature radii r = 30 and 60 mm via (a) transmission and reception dynamic focusing; and (b) only reception dynamic focusing with respect to a spherical diverging transmission wave.

were mechanically scanned by a 2D linear-array-type probe (Ueda Japan Radio Co., Ltd., 16 × 16 elements, 1.5 MHz, 0.4 × 0.4 mm pitches) set at the surface of a water with rf-echo data acquisition system with a motorized positioner (Japan Probe Co., Ltd., 20 MHz) to acquire 64 × 64 × 1500 monostatic SA data. Here, 2 independent virtual point sources were respectively set behind the mechanical scanning volume with different distances (r = 30, 60 mm) to virtually form 2 spherically 2D-arrayed aperture probes with different curvature radii r.

Fig. 2 shows images of x-y and z-y planes obtained by (a) transmission and reception dynamic focusing; and (b) only reception dynamic focusing with respect to a spherical diverging wave transmission. In both beamformings, images of targets were successfully formed. Normally, r increasing, the lateral resolutions decreased; and the lateral resolutions were higher for (a) than (b). As shown in **Fig. 3**, the lateral circulation artifacts shown in **Fig. 2(b)** were able to be coped with by padding zeros into the surrounding of raw echo data.

Next, delays were also artificially set during the calculations as mentioned above. For instance, with respect to **Fig. 2(a)**, targets slightly pi-shaped in an x-y plane and running in the z-direction were

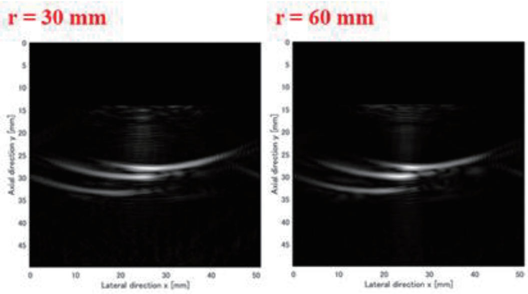

Fig. 3 Echo images with no lateral circulation artifacts shown in Fig. 2(b), which are obtained by padding zeros into the surrounding of raw echo data.

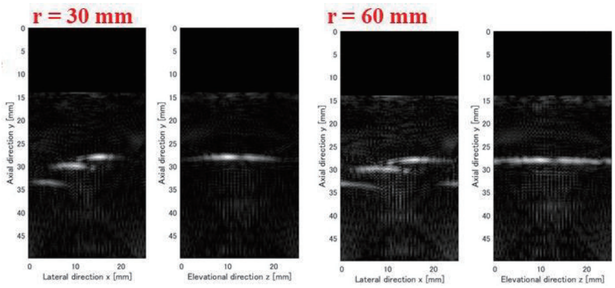

Fig. 4 Echo images obtained with delays artificially set during calculations for Fig. 2(a).

clearly imaged as shown in **Fig. 4**. Such processing can also be categorized into a virtual source processing.

4. Conclusions

Using a virtual source set behind a 2D linear-array-type probe, image formations were experimentally achieved with respect to wire phantoms. In terms of a calculation speed, this Fourier beamforming is more effective in 3D than 2D beamforming (omitted). Similarly to our previously reported calculation for a plane wave transmission [1], by performing the calculation for the diverging wave transmission, single or plural physically arbitrary transmission waves can also be processed (not shown here). Next, various applications including for a deformable aperture will be reported.

References

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3. C. Sumi and T. Asakawa: Proc of 2019 IEEE Int Ultrason Symp to be published.