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Experimental Validation of Displacement Vector Measurement Based on 2D Modulation Method with Virtual Hyperbolic Scanning

仮想双曲線走査による２次元変調を用いた変位ベクトル計測の実験的検討

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1. Introduction

Various methods measuring multidimensional displacement have been developed. Generally the accuracy of measured displacement vector is high in beam direction, while it is low in lateral direction because the point spread function constituted by RF signals represents acoustically-oscillated pattern in beam direction but not in lateral direction. The lateral modulation method was proposed by Jensen et al.[1)] for blood flow measurement. The method is a unique approach to measuring lateral displacement with high precision by generating a laterally oscillating RF signal. However, it is designed only for linear scanning, and so its modulating area is restricted by aperture size.

In the previous work, we proposed a new method that can generate modulated RF signals with oscillation in two mutually orthogonal directions over a wide, deep area using a small aperture probe[(2,3]. In this work, we applied the method to elasticity imaging and validated its feasibility by phantom experiments.

2. Methods

We proposed a 2D modulation method with hyperbolic scanning[(2,3]. It has the merit that aperture size can be kept constant without reducing the lateral modulation frequency in deep regions, so it is appropriate for sector scanning to measure a wider region with a small aperture. The modulated signal is obtained by choosing the sampling points at the intersections of the hyperbola and ellipsoid for RF signals oscillating in two mutually orthogonal directions (**Fig. 1**). An apodization function for 2D-modulating RF is defined as superposition of two Gaussian functions with peak points at one quarter from both ends of the aperture respectively, and is constant with depth. The sampling points (x_{ij}, y_{ij}) for line index i and range index j are defined as follow:

$$\begin{pmatrix} x_{ij} \\ y_{ij} \end{pmatrix} = \begin{pmatrix} \dfrac{\frac{1}{2}cTi\left(\frac{1}{2}cTj+f\right)}{f} \\ \dfrac{\sqrt{\left((\frac{1}{2}cTj)^2+2\frac{1}{2}cTjf\right)\left(f^2-(\frac{1}{2}cTi)^2\right)}}{f} \end{pmatrix}, \qquad (1)$$

where c is the speed of sound, T is the sampling period, f is the distance between the center of the aperture and the peak of the apodization.

Synthetic aperture imaging technique is performed to focus on such sampling points in scanning beam line along hyperbola. In practical experiments, the SNR of point-source transmission is not high enough to measure displacement, so we employ a coded excitation to improve the SNR. In this paper, Hadamard spatial coding[4)] is used. It excites all elements simultaneously with phase-encoding based on an Hadamard matrix. It requires the same number of transmissions as that of point-source transmissions in synthetic aperture imaging, and no additional measurements are needed. After all transmissions are performed, each point-source measurements are separately acquired with high SNR by decoding post-process. Then synthetic aperture imaging is calculated using

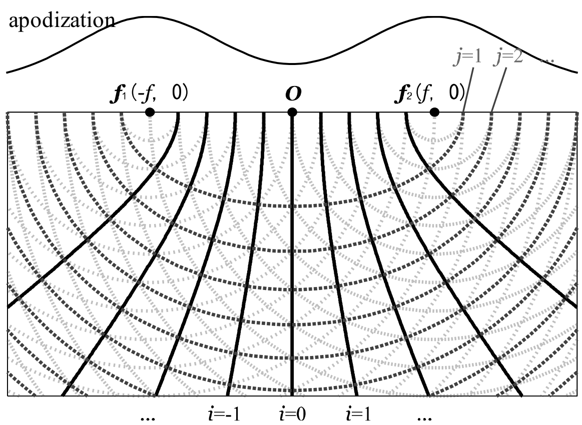

Fig. 1 The virtual hyperbolic scanning path and apodization for a 2D-modulation.

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decoded point-source measurements.

The acquired 2D-modulated RF signals are used to estimate a 2D displacement vector by using the phase-shifts of the two oscillations.

3. Phantom Experiments

We validated the availability of the method by phantom experiments. A 5 MHz linear array probe with a 19.2 mm aperture was used for phantom experiments.

First, wire targets at several positions were measured to observe the point spread functions (**Fig. 2**). The obtained RFs around wire targets are shown in **Fig. 3**. In contrast to conventional beamforming indicating oscillation only in axial direction (Fig. 3 (a)), 2D-modulation generates both lateral and axial oscillations (Fig. 3(b)-(d)). It shows that uniform PSF are generated as designed at least to 50mm depth and 25 mm lateral position, where is outside of the probe aperture.

Next, an agar phantom with a hard inclusion (9mm diameter cylinder) was used to evaluate the applicability of the proposed method to measuring lateral displacement in an elasticity image (**Fig. 4**). The phantom was compressed laterally, and the strain distribution of the phantom was measured. The estimated strain distribution is shown in **Fig. 5**. Fig. 5 (a) shows that the x-direction strain enables us to distinguish the hard inclusion from surrounding media. In addition, Fig. 5 (b) represents that the y-direction strain induced by x-direction compression is also obtained in high accuracy.

4. Conclusion

We validated the applicability of our proposed method by phantom experiments. The wire experiment demonstrated that the modulation was performed as designed in a deep, wide area and even outside the probe aperture. The inclusion phantom experiments demonstrated that the 2D-modulated RF signals generated by the proposed method can detect axial and lateral displacement and can obtain quantitative elasticity images.

References

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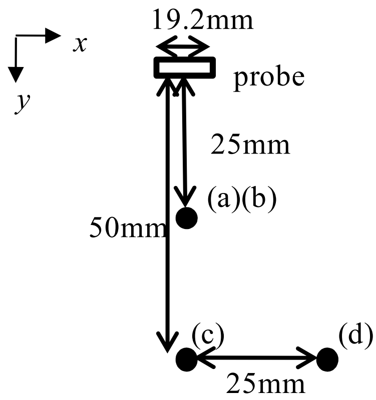

Fig. 2 Schematic of wire targets measurement.

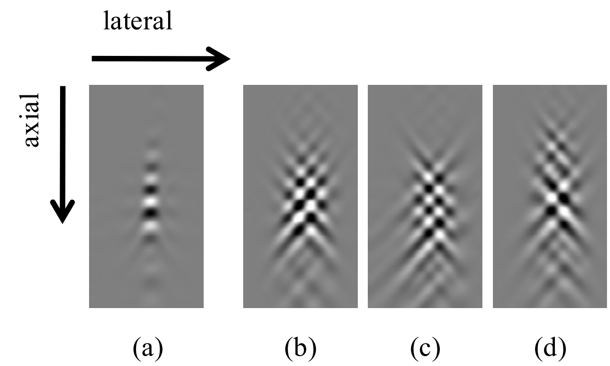

Fig. 3 RF patterns for a wire target obtained by
(a) conventional beamforming for (x, y) = (0, 25)
(b)-(d) 2D-modulation for (b) (x, y) = (0, 25), (c) (x, y) = (0, 50) and (d) (x, y) = (25, 50).

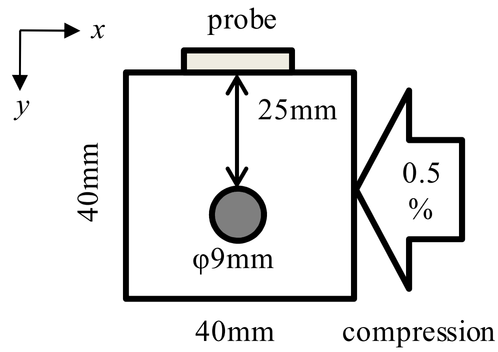

Fig. 4 Lateral compression of an agar phantom with hard inclusion. The surrounding medium is 1% agar and the inclusion is 5% agar.

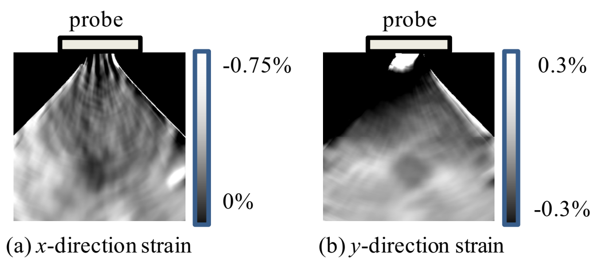

Fig. 5 Estimated strain in x-direction and y-direction.