047 **BEAM STEERING WITH POST-INCREASING LATERAL BANDWIDTH FOR HIGH SPATIAL RESOLUTION ECHO IMAGING AND HIGH ACCURACY DISPLACEMENT/ELASTICITY MEASUREMENT –DEMONSTRATION ON SMALL INCLUSION AGAR PHANTOMS.**

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Summary: High accuracy measurements are performed on agar phantoms having very small cylindrical stiff inclusions (i.e., dia. 3 and 5mm) that are laterally compressed. Our previously developed lateral modulation (LM) is performed together with coherent superposition and use of over-determined systems (i.e., averaging and LST).

1. Introduction

When performing beam steering for such as a sector or our proposed lateral modulation (LM) scanning (e.g., [1,2]), if an ultrasound (US) element pitch or a beam pitch is large, or if a steering angle is made too large to obtain a large field of view or a large lateral frequency and bandwidth, aliasing occurs. A properly generated large steering angle increases a lateral resolution and measurement accuracies of a lateral displacement and a lateral strain. Then, we previously proposed a method for increasing a lateral bandwidth, i.e., through performing zero spectra padding in a frequency domain after physically completing beamforming [1,2]. As far, we showed only B-mode images obtained using the method [1].

In this study, the method was used for high spatial resolution measuring displacements/elasticity (strains, shear moduli etc.) using a special transducer and beamforming parameters, particularly on agar phantoms having very small cylindrical stiff inclusions (i.e., dia. 3 and 5mm) that were laterally compressed [2]. LM was performed. Steered plane wave transmissions were also performed via synthetic aperture (SA) processing [3]. Other previously developed methods were also used, e.g., coherent superposition; over-determined systems (i.e., averaging and LST) (e.g., [4]).

2. Agar phantom experiments

2.1 Methods

(A) Spherical focused transmissions

The transducer was specially manufactured to have a small element pitch (0.1 mm) rather than commercial ones. Experiments were performed using three kinds of beams generated through SA processing with respect to same raw echo data (US frequency, 7.5 MHz; wavelength, λ). Parabolic apodization was performed to obtain a high lateral resolution [3].

(i). Echo data were generated with the same pitch as the element pitch, and a lateral wavelength (LW) 2λ was achieved with no aliasing;

(ii). For echo data aliased with respect to LW 2λ, which were generated with the twofold pitch (0.2 mm) through addition of adjacently received raw echo data, the aliasing was removed using the method;

(iii) Echo data with LW λ were generated with no aliasing from echo data (i) by making the beam pitch 0.05 mm with the method.

For comparison,

(iv) Other echo data were also generated through the coherent superposition (e.g., [4]) of echo data (i) and (iii);

and (v) Over-determined systems were also generated from echo data (i) and (iii), i.e, the least squares (LST) measurements and averaging (AVE) measurements were performed (e.g., [4]).

(B) Plane wave transmissions

Next, plane wave transmissions were performed with Gaussian apodization [4]. LWs 2λ and λ (with the method) were generated. With respect to the LW 2λ, beams were also steered with additional angles, $\pm 1°$ and $\pm 2°$. Similarly to (A), elasticity was measured. That is, the measurements were respectively performed on LWs 2λ and λ, respectively; and coherent superpositions and over-determined systems were generated on the LWs 2λ and λ, and $2\lambda \pm 1°$ and $\pm 2°$.

2.2 Results

(A) Spherical focused transmissions

The measurement accuracies depend on various parameters such as a window size, an echo SNR, etc. For instance, when our previously developed multidimensional autocorrelation method (MAM) [4] was used with a window size, 1.0×2.4 mm², the measurement accuracies of strains and shear moduli (Fig. 1, 5 mm; Fig. 2, 3 mm) were evaluated statistically (Fig. 2). Even for echo data (i) with LW 2λ obtained without the method for increasing the lateral bandwidth, accurate measurements were achieved (the small circular inclusions were detected). Even with the method, the echo data (ii) were not useful for the measurements (the inclusion shapes were distorted and omitted), although LM echo imaging was achieved (omitted). For echo data (iii), the method was effective in yielding a large lateral frequency but a narrow bandwidth echo image (LW, λ; Fig. 4); and high measurement accuracies and stabilities (Fig. 3). However, the smaller LW decreased the measurement accuracies due to decreasing an echo SNR (omitted). The order of accuracies was LST > coherent superposition = AVE > (iii) > (i) > (ii) [for lateral strains in a 5mm inclusion, about means, -0.5%; SDs, 0.23, 0.24, 0.24, 0.28, 0.30, 0.70%]. When using a smaller window, the order changed, and for instance, for 0.5 mm×2.4 mm², the method was not effective, i.e., (i) > AVE > LST > coherent superposition > (iii) > (ii). As previously confirmed in ref. [4], when local echo data had a low echo SNR, AVE is more effective than LST. For a rather high echo SNR, the coherent superposition has a trend in yielding a lower measurement accuracy than such over-determined systems, although a higher spatial resolution echo imaging can be performed (Fig. 4). Moreover, as previously confirmed, MAM allows measuring a high accuracy lateral displacement but also a higher accuracy axial displacement than a conventional axial

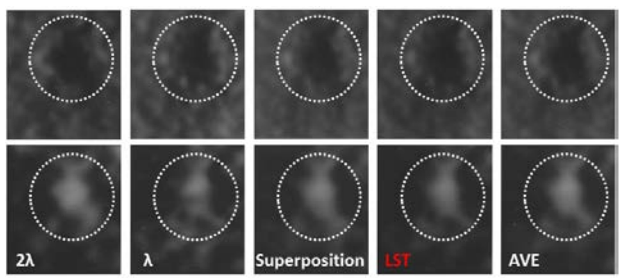
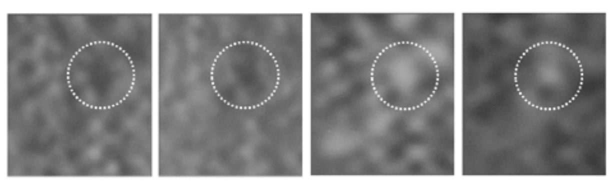
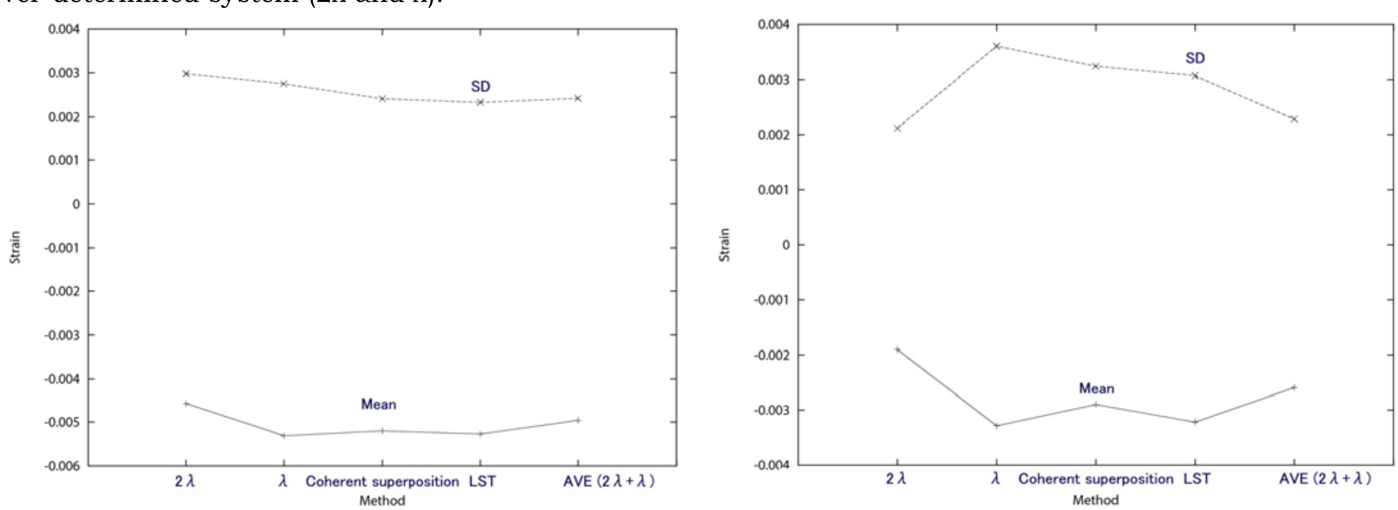


Fig. 1. Lateral strains (upper) and shear moduli (lower) obtained for 5 mm dia. inclusion agar phantom. Window size, 1.0×2.4 mm².



Lateral strains Shear modulus

Fig. 2. Lateral strains and shear moduli obtained for 3 mm dia. inclusion agar phantom. (left) 2λ and (right) over-determined system (2λ and λ).



(a) (b)

Fig. 3. Means and SDs evaluated in 5 mm dia. inclusion (agar phantom). Window sizes, (a) 0.5×2.4 mm²; (b) 1.0×2.4 mm².

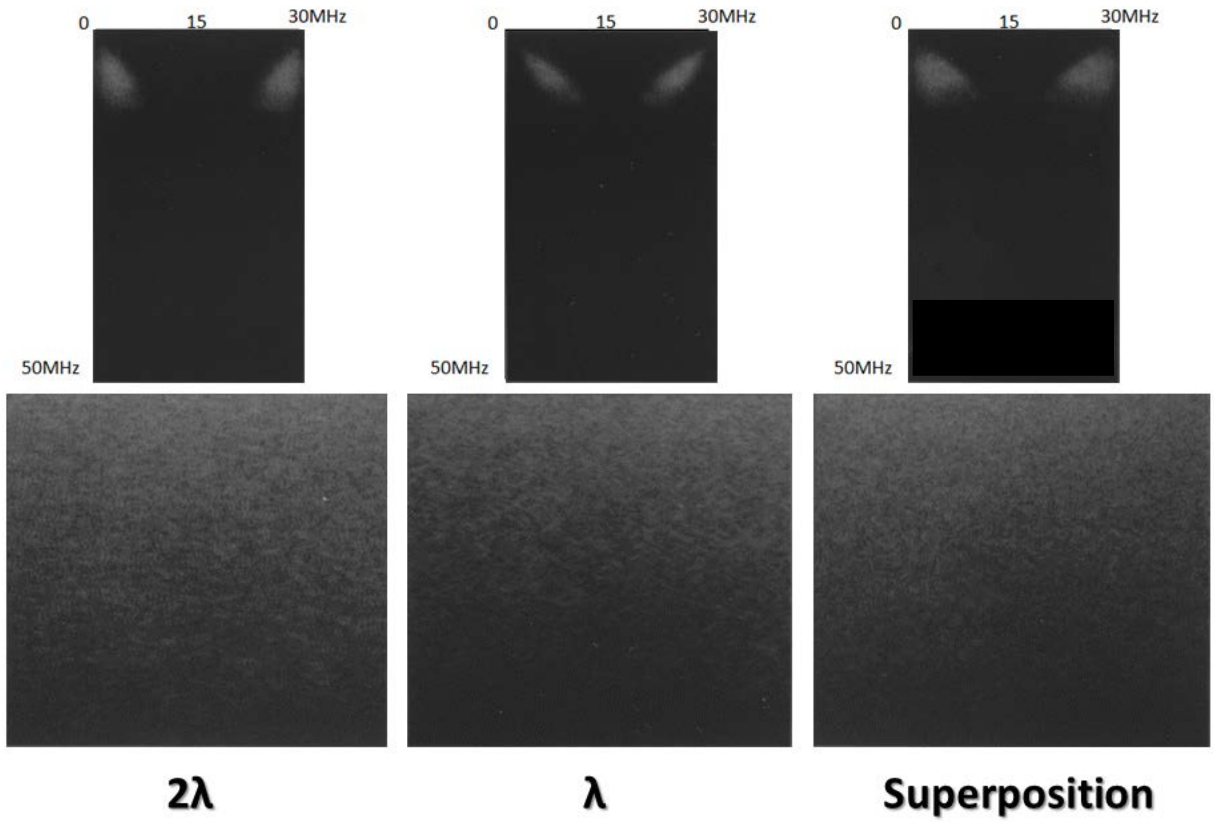


Fig. 4. B-mode images obtained for 5mm dia. inclusion agar phantom.

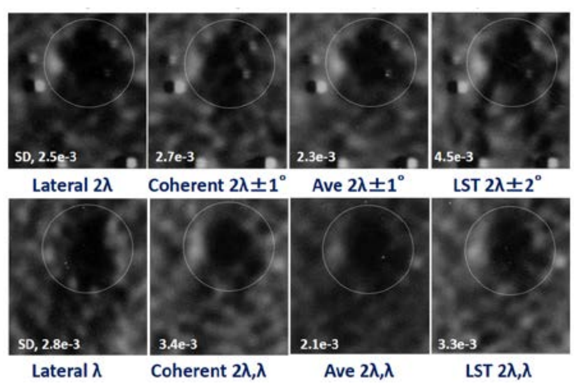


Fig. 5. Lateral strains obtained for 5 mm dia. inclusion agar phantom using plane wave transmissions. Window size, 1.0×2.4 mm^2.

measurement (omitted).

(B) Plane wave transmiisios

Fig. 5 shows the measurement results of a lateral strain with SDs evaluated in a 5mm dia. inclusion. The plane wave transmissions yielded lower echo SNRs than the spherical focused transmissions. As predicted, in such a condition, LST yielded a lower measurement accuracy than the coherent superposition, and the averaging measurement yielded the highest measurement accuracy of all. The independent spectra (i.e., LWs 2λ and λ) yields higher accuracies than spectra with $2\lambda \pm 1°$ and $\pm 2°$. The inclusion was measured to be more circular via the uses of independent plural waves.

3. Conclusions

Because the ultrasound system was slightly noisy, the measurements became less accurate than the results obtained using another systems (e.g., a 10 mm dia inclusion case [5]). However, using the method, even when performing spatially sparsely beamforming or the Nyquist theorem was not satisfied with, such a large steering angle was achieved; high frame rate echo imaging and accurate measurements was also achieved. The uses of plural beams were also effective. In addition, other previously developed methods were also used, e.g., steered plane wave transmissions, coherent superposition; over-determined systems (i.e., averaging; LST) (e.g., [3,4]). Independency of spectra was also critical. Combinational high spatial resolution echo imaging was effective. Together with spectra division method (e.g., [3]), these methods will be effective for measurements of various rapid and complex tissue motions and shear wave propagations etc.

References

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