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Implementation of Accurate Tissue Motion Estimate via High-Resolution Synthetic Aperture Array Signal Processing

高分解能配列開口合成処理における組織変位推定の高精度化

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1. Introduction

For realizing ultrahigh-frame-rate ultrasonic simultaneous imaging of microdynamics in a living soft tissue, a one-way synthetic aperture (SA) array processing is essential toward a real-time-received two dimensional (2D) echo signal followed by a successive irradiation from the array transducer. In our proposed system integration the irradiation field is controlled by the localization and power of two point sources in alternate generetions for the measurement of the 2D tissue motion vector across a target plane covered by the 2D echo signal, to avoid ordinary artifacts in vivo [1-4].

Herein, the overall system performance in evaluation of the 2D local motion vector is analyzed in accuracy, statistical variation and spatial resolution by taking account of local cross correlation between two successive 2D echo signals. Especially the interaction between point spread function (p.s.f.) of SA array processing system and statistical moving average window (m.a.w.) for evaluating the local cross correlation is numerically investigated to clarify practical tradeoff of the sysytem parameter setup for 2D motion vector estimate in a living tissue.

The simulations are performed for 2D echo signals showing fully developed speckle [5] obtained from uniformly distributed point targets with normally distributed random reflectivity. The transmitting and receiving system system is conducted by a conventional linear array transducer having 256 elements with a 0.25 mm pitch and a 3.0 MHz center frequency, in which the evaluation can be verified in our integrated experimental setup of SA array signal processing system [1-4].

2. Evaluation by Plane Wave Irradiation

As a reference to compare with motion estimate by point source irradiations, the estimation variance for small range displacement (Δx=1, 10 μm) across a target plane (20 x 16 mm) of which center is positioned at (50 mm, 0 mm) by plane wave incidences was evaluated as shown in Fig. 1.

Though the maximum performance is recognized for each typical p.s.f. as the change of normalized standard deviation (nsd) vs. range to cross-range ratio of m.a.w. having a fixed area of 9 mm^2, the nsd around 10^{-1} for 10 μm displacement in arbitrary direction is required as a practical goal by utilizing alternate point source irradiations.

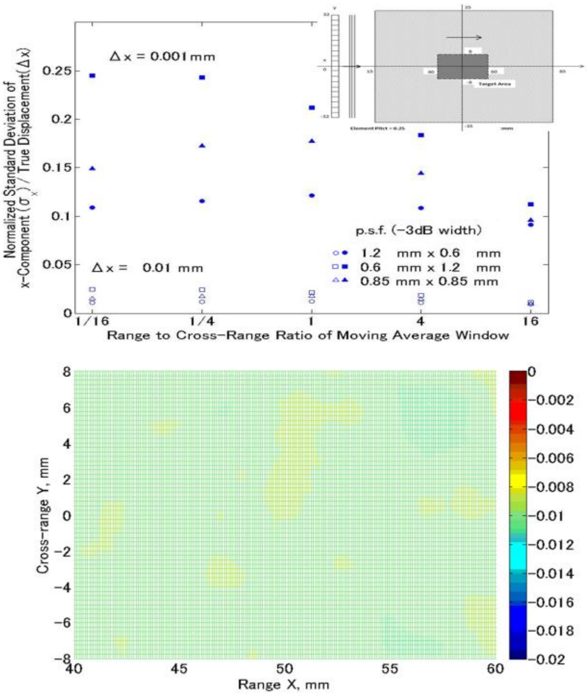

Fig. 1 Property of range motion estimate by plane wave irradiations.

3. Evaluation by Irradiation from Point Source

The two point sources (A, B) for alternate irradiations are located at (8mm, 16mm) and (8mm, -16mm). It is difficult to adjust the geometry of p.s.f. smaller than m.a.w. for accurate evaluation of arbitral motion vector. Thus the range and cross-range displacement of 10 μm were evaluated separately in each orthogonal component across the target plane as shown in Fig. 2 and Fig. 3, respectively. Though the evaluated vector components indicate a little higher accuracy for range motion than cross-range motion of 10 μm, the entire evaluation in accuracy and variance is satisfactory for the practical applications.

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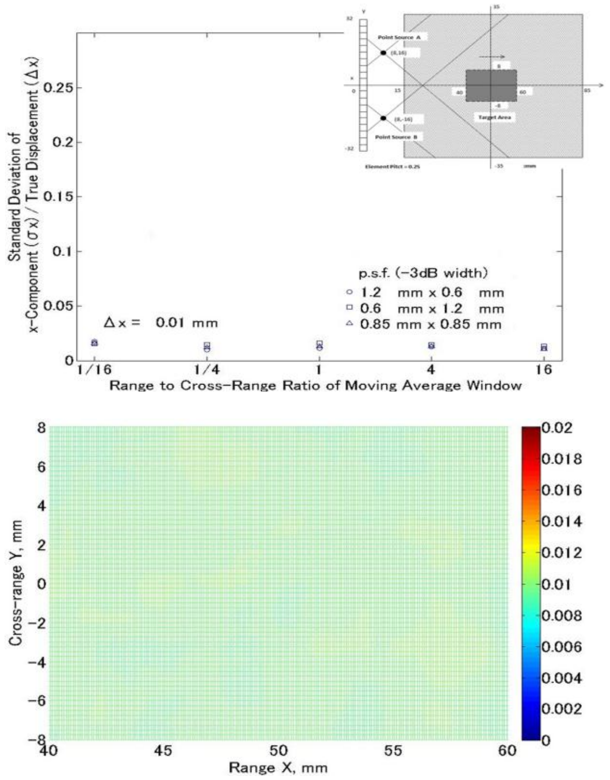

Fig. 2 Property of range motion estimate by point source irradiations.

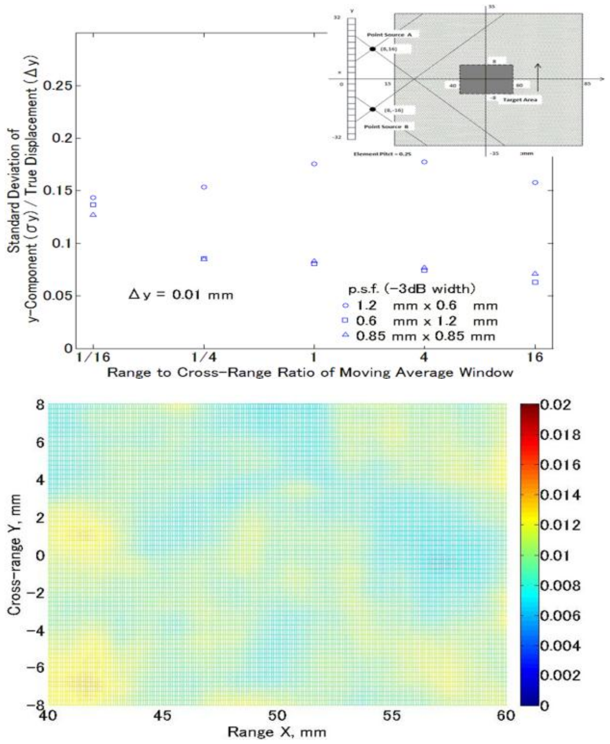

Fig. 3 Property of cross-range motion estimate by point source irradiations.

4. Spatial Resolution of Displacement Vector

The spatial movements evaluated for stepwise displacement of 10 μm at the center of the target plane in both range and cross-rage directions are depicted as shown in Fig. 4 and Fig. 5, respectively. From these results the spatial resolution (-3dB width) calculated from the gradient of the averaged displacement was 2 mm by 2.5 mm in orthogonal geometry.

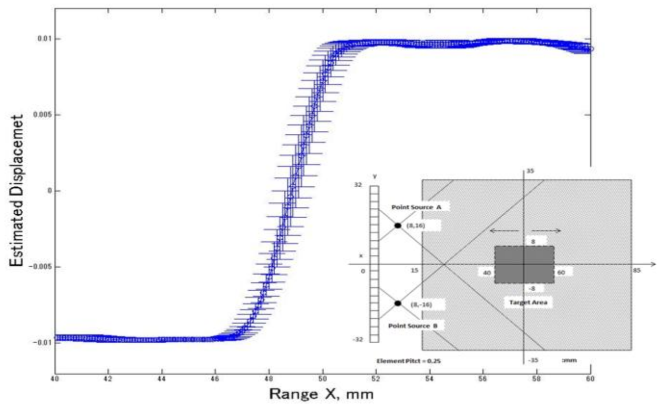

Fig. 4 Spatial Evaluation of stepwise range motion.

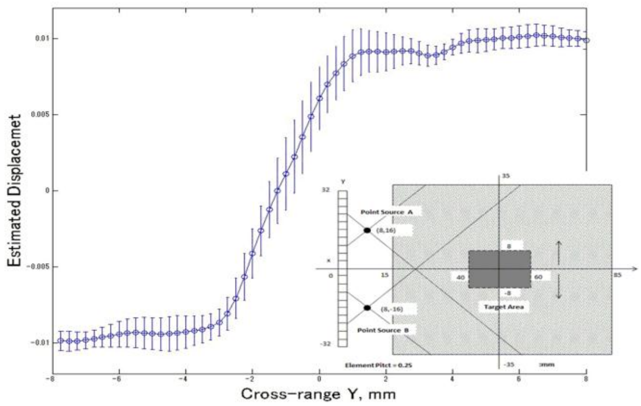

Fig. 5 Spatial Evaluation of stepwise cross-range motion.

5. Conclusion

The simulation result shows an practical performance of the SA array processing system to realize ultrahigh-frame-rate ultrasonic simultaneous imaging of tissue microdynamics in accuracy, variance and resolution. Further accuracy of tissue motion estimate would be investigated in high resolution imaging by nonlinear spectral analysis.

References

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