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An apodization in Finite Array Synthetic Aperture Processing for Accurate Motion Estimate in Living Tissue

有限配列開口合成処理における高精度組織変位計測のためのアポダイゼーションの改善

Daiki Sugeno[1†],Shin-ichi Yagi[1],Kiyoshi Tamura[2],Masakazu Sato[3]
([1]Graduate Schol of Information Science, Meisei Univ; [2]New Technology Planning Department, Hitachi Aloka Medical Ltd; [3]R & D Department, Microsonic Ltd)
菅野　大希 [1†], 八木　晋一 [1],田村　清 [2], 佐藤　正和 [3] ([1] 明星大学大学院情報学研究科, [2] 日立アロカメディカル株式会社新技術企画室, [3] マイクロソニック株式会社研究開発部)

1. Introduction

Synthetic aperture (SA) array signal processing utilizing a finite array transducer is an essential key technology enabling ultrasonic high frame rate imaging with a controllable high-resolution, as well as a breakthrough in recent transient elastography, which is providing advances in the medical diagnosis of living soft tissue in vivo [1)]. Using the technology to detect small tissue movement of subwavelength order the authors have executed forward measurement system design in the spatial frequency domain for lowering the calculation cost and expanding the prospect in the performance estimation of the entire measurement system [2-3)].

The proposed system introduces a pair of pulsed sound field irradiations from each point sound source which is virtually generated at a focal point of the array transducer for the local phase difference estimation between each SA reconstructed successive speckle echo data throughout the random tissue medium. Thus, the local motion vector can be calculated from the pair of the phase differences in accordance with successive irradiating and parallel receiving by the array transducer. However, the point spread function (PSF) of a finite-array SA reconstruction system is accompanied by spatial alteration at the phase level according to the azimuthal asymmetry of the acquired 2-dimensional echo signal by azimuthal target deviation from the range axis passing through the center of an aperture. This spatial alteration is quite sensitive and generates serious errors in the local phase difference estimation between speckle echo frames. An apodization in the spatial frequency domain is proposed to restrict the unnecessary spatial frequency component in the azimuth direction to carry out the reconstruction of theindividual range stacking segments in a SA array signal processing algorithm[3)]. Herein, the performances of the original and apodized reconstruction PSFs are analyzed to verify an alteration for the extension of the measurement region within practical estimation error[4)] and further optimization of the system design.

2. PSF of finite-array SA reconstruction system

The simulation analysis was accomplished by an array transducer, in which 256 elements with a central frequency of 3 MHz are arranged at an element pitch of 0.25 mm for a virtual sound source irradiation at the position of (8 mm, 16 mm) in x, y coordinate with the origin at the array transducer, and point targets at even intervals as shown in Fig. 1.

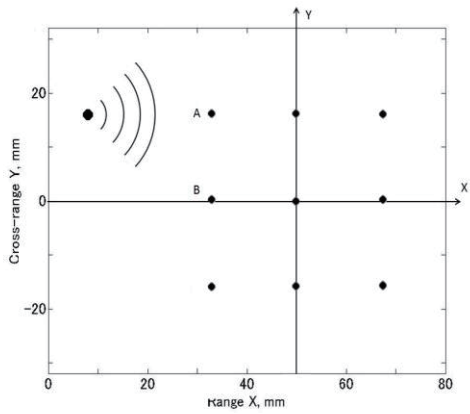

Fig.1 Simulation model of finite-array SA reconstruction system.

The SA reconstructed echo images of these targets are depicted in Fig. 2 across the measurement area with its central position of (50 mm, 0 mm).

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suge@con.ei.meisei-u.ac.jp

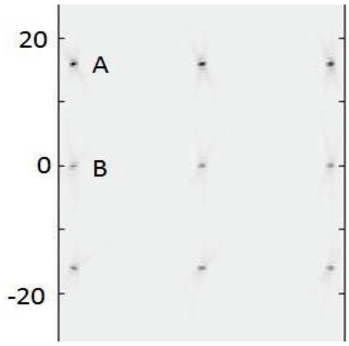


Fig.2 Images of reconstructed sqecular echoes.

For making a thorough understanding of the spatial performance of the finite-array SA reconstruction system, which causes serious errors in the local phase difference estimation, the two reconstructed RF PSFs normalized by each amplitude distribution are depicted in Figs. 3(a) and 3(b), for a target position of A and B, respectively. Because of such performance accompanied by complicated distribution at the phase level, it should be directionally sinusoidal to detect a local phase difference between the reconstructed speckle echo frames, according to the directional irradiation from a virtual point source.

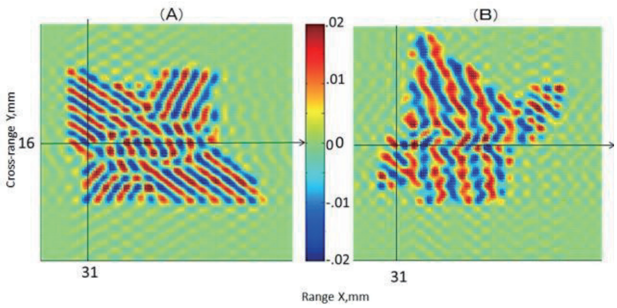
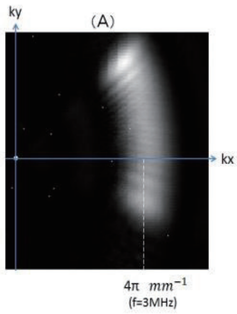


Fig.3 2D phase distribution of RF-PSFs at a position of A and B.

3. Apodization in the spatial frequency domain in range stacking SA processing

To improve the directional phase coherency of finite-array SA reconstruction system, it is necessary to restrict the unnecessary spatial frequency component to comply with the azimuth asymmetry of the 2-dimensional echo signal, which is observed in the spatial frequency spectrum of the reconstructed RF PSF in k_x, k_y coordinate, as shown in Fig. 4.

Thus, dynamic windowing of the spatial frequency spectrum in the azimuth direction has been successfully carried out in the individual range stacking segments with a small range interval in which successive SA reconstruction processing is performed. Herein, the Kaiser window in Fig. 5, which can eliminate unnecessary band without a serious influence on the resolution and can control adequate symmetric weighting of the effective band adjusting a single parameter (α) is introduced. As a result, the apodization performances for the previous two RF PFSs of finite-array SA reconstruction system indicate both the similarly improved sinusoidal phase coherencies, according to the directional irradiation from a virtual point source to target A and B, as displayed in Fig. 6(a) and 6(b), respectively.



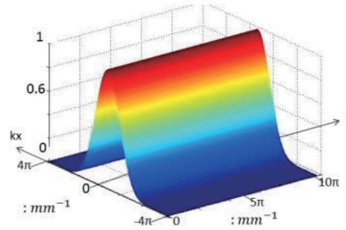


Fig.4 Spatial frequency spectra of reconstructed RF-PSFs at position of A.

Fig.5 Apodization window.

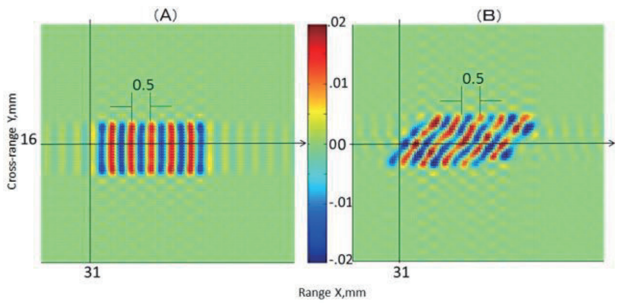


Fig.6 Directional phase variations of apodized RF-PSFs at a position of A and B.

4. Conclusions

The useful performance of the proposed SA reconstruction algorithm complying with a finite array transducer was verified in detection of accurate dynamic information for medical diagnosis of living soft tissue in vivo with a high frame rate. The experimental data obtained using a tissue phantom and further optimization of the system design will be referred elsewhere.

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