087 **2ND REPORT ON PROPER POINT SPREAD FUNCTION FOR LATERAL MODULATION.**

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(Figure 4 corrected on February 26, 2010)

1. Introduction

We have realized the beamformings [1–3], by using beam steering and apodization, for accurately measuring tissue or blood displacement vectors or strain tensors [4] using the multidimensional cross–spectrum phase gradient method (MCSPGM), and autocorrelation and Doppler methods (MAM and MDM). In [1-4], we reported lateral modulation methods (LMMs) that use several apodization functions in addition to the multidirectional synthetic aperture method (MDSAM) and the multiple transmitting method (MTM). As shown, the coherent superimposition of the steered beams performed in LCMM has a higher potential for realizing a more accurate measurement of a displacement vector than the synthesis of the displacement vector using the accurately measured axial displacements performed in MDSAM and MTM. However, in LMMs, MDSAM and MTM can also be used to obtain multiple steered beams. If necessary, multiple transducers are also used (e.g., for heart). These modulations can also be used for B–mode imaging simultaneously [1-3].

For these beamformings, in [1-3], we also reported more proper apodization functions than that expressed using Gaussian functions we proposed previously, e.g., that using parabolic functions. Echo data having wider lateral bandwidths and higher signal–to–noise ratios (SNRs) can be obtained. Such echo data can also be obtained by realizing a proper point spread function (PSF) of which envelope has a wide FWHM and short feet such as a parabolic function (PA) rather than a Gaussian function (GA) [5]. In order to obtain a better approximation of such a PSF than that obtained by Fraunhofer approximation, we also developed optimization methods [2,5] for yielding the best apodization function in a linear least squares sense and a nonlinear manner (i.e., truncation of the feet of the apodization function).

In this study, the better envelope shape of the PSF than PA is searched for on the basis of the knowledge about the ideal shape obtained previously [5], i.e., having a wide FWHM and short feet. The properness is examined by evaluating the accuracy for a displacement vector measurement.

2. Methods

The candidates of more proper envelopes than PA are selected from representative analytic windows (MatLab etc) by drawing the windows having a same energy. For the candidates, independent laterally modulated echo data are simulated using white data, of which spectra are compared. In addition, the accuracies of the 2D displacement vector measurements are also compared. Strains (0.1–2%) are simulated (ultrasound frequency = lateral modulation frequency fy, 1–5 MHz; axial and lateral SDs for GA, 0.4-1.2 mm; echo SNR, 10–30 dB).

3. Results

For the candidates, power functions (power order, n >= 2), and Akaike (see Fig. 1) and rectangular windows were obtained. n was changed up to 20. These functions can be obtained by comparing their FWHMs and feet with those of Bartlett, Bartlett-Hann, Blackman, Blackman-Harris, Blackman-Nuttall, Parazen, Nuttall, Flap-top, Kaiser, and Chebychef etc. n increasing, the power function approaches to a rectangular function. As the simulation result of a displacement measurement, the measurement accuracy by the rectangular envelope is the best of all. The measurement accuracies obtained for the candidates are shown in Fig. 2 (SDs of 0.4 mm (GA) and frequencies of 3.5 MHz).

Moreover, as a proper envelope, a new window was also obtained by changing Hanning windows by power functions in Turkey window. See Fig. 3, in which r is a relative length of direct current with respect to a total length. For comparison, a rectangular window and PA were also used again. For instance, when

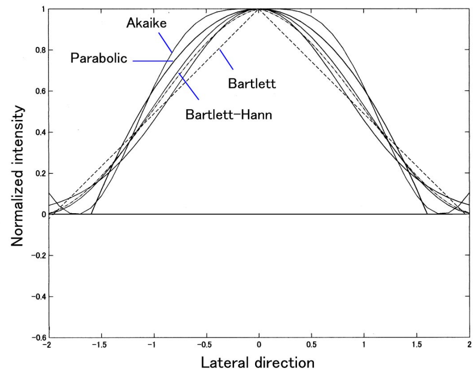
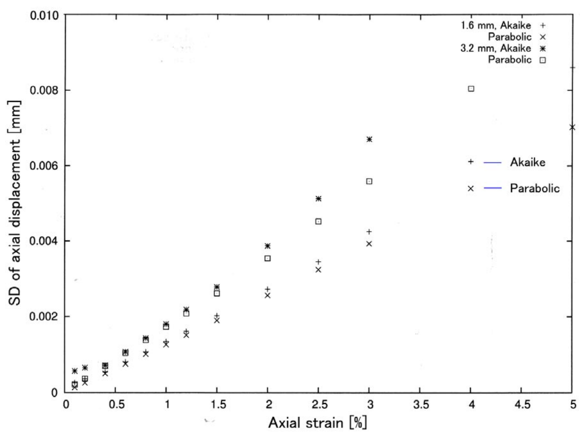
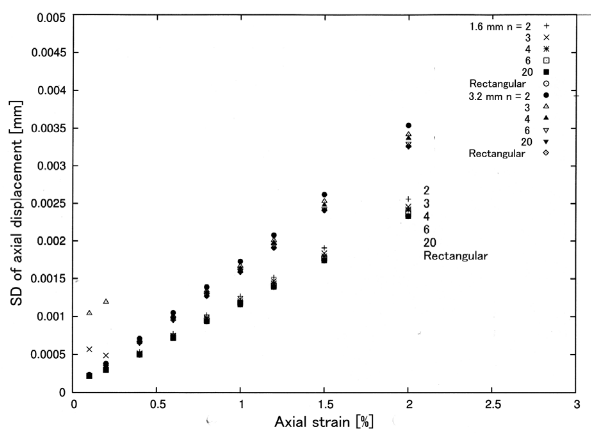


Fig. 1. Drawings of Akaike window and PA with Bartlett windows.



(a)



(b)

Fig. 2. (a) Parabolic function (PA) vs Akaike, and (b) power functions (n>2) and rectangular window for 30 dB echo SNR.

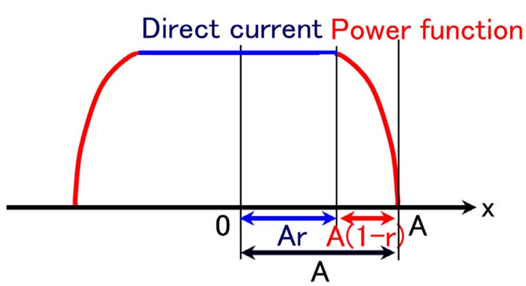


Fig. 3. A new function.

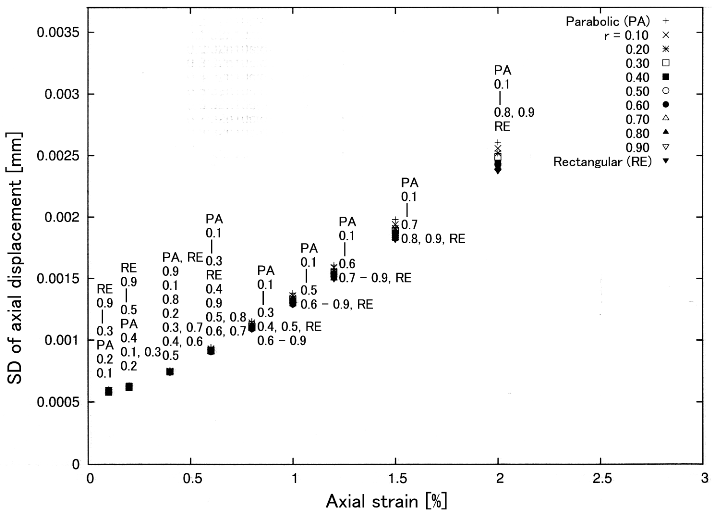


Fig. 4. New functions using r = 0.10 to 0.90, PA, and rectangular window.

10 dB echo SNR, SDs of 0.4 mm, and frequencies of 3.5 MHz, see Fig. 4. For small strains (0.1–0.8 %), the order of the measurement accuracy of axial displacement was, new function (n = 2) > rectangular window.

4. Conclusions

Using proper PSFs obtained, the accuracy of a displacement vector measurement was improved. The order of accuracies are, a new function > rectangular window, power function (a higher order) > PA > Akaike window. The new function with higher order (n>2) power functions will be better than that with parabolic functions. The proper PSFs will also improve the image quality.

For the proper PSFs, the Fraunhofer approximation (FA) and linear and nonlinear optimizations [5] will be performed such that the corresponding best apodization functions can also be obtained. That is, the nonlinear optimization will be useful. The better PSF will also be searched for by an analogue design, a dynamic programming etc.

References

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