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Improvement of performance of minimum variance beamformer by Nakagami shape parameter
仲上形状パラメータによる最小分散ビームフォーミングの性能向上

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1. Introduction

Ultrasound imaging is an important modality used in medical imaging. The delay-and-sum (DAS) beamformer is widely used in ultrasound imaging systems. Since the DAS beamformer has the disadvantage of poor resolution, the minimum variance (MV) [1,2)] beamformer was introduced in ultrasound imaging as a more adaptive beamformer. The MV beamformer provides better resolution than the DAS, however the contrast is reduced.

In this study, we aimed to improve the contrast while maintaining the resolution of the conventional MV method by discriminating the speckle and other regions using a parameter that determines the shape of the Nakagami distribution, which is a general model for the statistical properties of ultrasonic echo amplitudes under all scattering conditions encountered in medical ultrasound imaging [3, 4)]. The performance of the proposed MV beamformer was controlled using the Nakagami shape parameter estimated from ultrasonic signals obtained by DAS beamforming.

2. Method

The probability density function (PDF) of the echo envelope amplitude from a number of randomly distributed scatterers, i.e., speckle regions, can be approximated by the Rayleigh distribution. The PDF of echo envelope amplitude is also expressed by the Nakagami statistical model given by[3)]

$$f(x)=\frac{2m^m}{\Gamma(m)\Omega^m}x^{2m-1}\exp\left(-\frac{m}{\Omega}x^2\right) \qquad (1)$$

where x is the echo envelope amplitude, Γ is the gamma function, Ω is the scaling parameter, and m is the Nakagami shape parameter. The Rayleigh distribution is equivalent to the Nakagami distribution when $m=1$.

It is possible to determine the echo characteristic in a region of interest by examining the value of $|m-1|$, because $|m-1|$ would be close to 0 in speckle regions. To take advantage of this property, we fitted the Nakagami distribution to the envelope obtained by DAS beamforming before

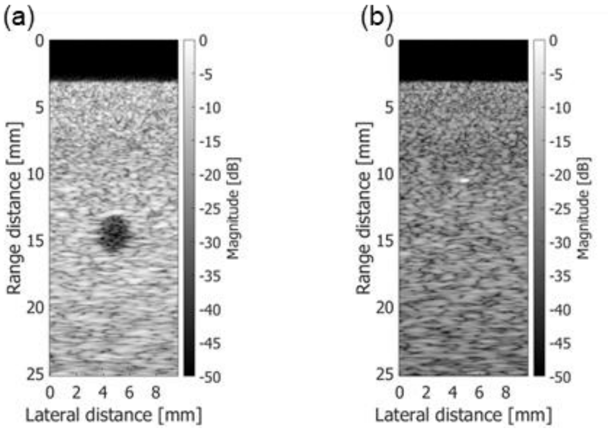

Fig. 1 B-mode images of anechoic cyst (a) and string (b) phantoms obtained by DAS beamforming.

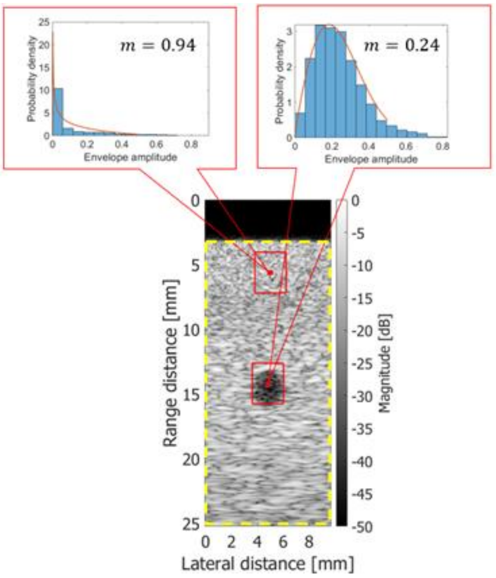

Fig. 2 Examples of PDFs of envelope in the analysis window. Nakagami distribution functions were fitted to PDFs obtained from the anechoic cyst phantom. The red solid lines indicate the estimated Nakagami distribution functions.

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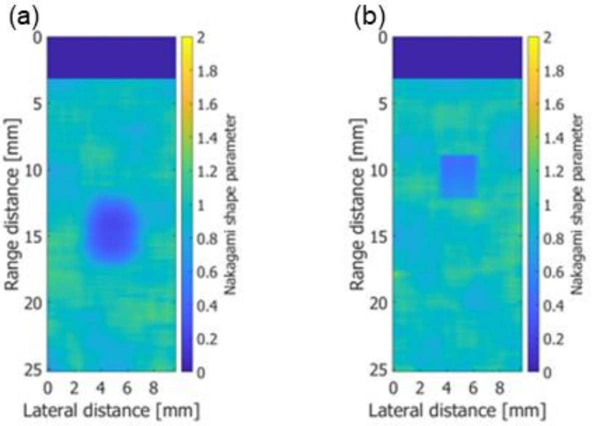

Fig 3 Spatial distributions of Nakagami shape parameters obtained from images in Fig. 1.

converting it into a B-mode image (**Fig. 1**). The m parameter was calculated at the window size of 2.4 × 3.1 mm^2 (in lateral × range directions) skipping with a pixel within the region surrounded by the yellow dashed line in **Fig. 2**. **Figures 3(a) and 3(b)** show the estimated values of m for cyst and string phantoms.

The performance of the MV beamformer can be controlled using a diagonal loading technique[5]. The estimated covariance matrix $\mathbf{R}$ in MV beamforming is expressed as

$$\mathbf{R} = \mathbf{R}' + \sigma \times \varepsilon \mathbf{I} \tag{2}$$

where $\mathbf{R}'$, σ, ε, and $\mathbf{I}$ are sample covariance matrix, diagonal loading parameter, total received energy, and identity matrix, respectively.

The proposed MV beamformer was carried out using the Nakagami shape parameter m. The constant σ is 0.1 in conventional MV method while the m parameter in **Fig. 3** determined σ to control the performance of the MV beamformer in the proposed method.

3. Result

The B-mode images obtained by the conventional and proposed methods with the MV beamformer are shown in **Fig. 4**. The speckle regions were more preserved in the proposed method than the conventional MV beamformer compared to the DAS images (**Fig. 1**).

The image quality of the proposed method was compared with that of DAS and conventional MV beamformers as shown in **Table I**. The degree of speckle, contrast, lesion detectability, and resolution were evaluated using contrast-to-noise ratio (CNR), contrast, generalized CNR (gCNR)[6], and full width at half maximum (FWHM) in the phantom. The contrast, CNR, and gCNR were compared between speckle and hypoechoic regions in the cyst phantom, and FWHM was computed from point spread function in the string phantom. The proposed method with MV beamformer improves the contrast about 0.6 dB against the conventional MV beamformer while maintaining the equivalent FWHM.

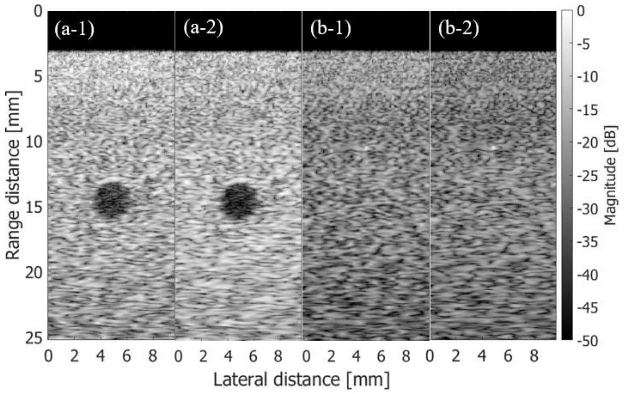

Fig 4 B-mode images of the anechoic cyst (a-1) and string (b-1) phantoms obtained using the conventional MV beamformer as well as two phantoms of (a-2) and (b-2) obtained by the proposed method with MV beamformer.

Table I Image quality among DAS, conventional and proposed methods with MV beamformer.

	DAS	**MV**	**MV (proposed)**
Contrast[dB]	-0.91	-1.26	-0.65
CNR [dB]	-84.7	-94.9	-105
gCNR	0.99	0.95	0.99
lateral FWHM [mm]	0.53	0.18	0.18
range FWHM [mm]	0.20	0.26	0.23

4. Conclusion

In this study, we developed the MV beamformer enhancing contrast and spatial resolutions using the Nakagami parameter. The proposed method with the MV beamformer performed preserving spatial resolution and higher contrast against the DAS and conventional MV beamformers. In future works, the parameter σ is controlled by mathematical function using the Nakagami parameter.

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