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Examination of generalized removal method of high-intensity non-speckle signals for echo-envelope statistics analysis

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1. Introduction

Echo-envelope statistics analysis is one of the effective approaches for biological tissue characterization. This approach is especially effective to evaluate the characteristics of speckle-like signals. However, in some cases, high-intensity non-speckle (NS) signals, such as signals from small blood vessels in liver, exist in echo signals obtained from biological tissues. These high-intensity NS signals affect the statistics of echo envelope and lead to a false evaluation of tissue characteristics of the speckle-like signals to be evaluated. In our previous study, we proposed a removal method of these high-intensity NS signals.[1)] However, this method is specialized to the multi-Rayleigh (MRA) model which is used to evaluate liver fibrosis.

This study aimed to examine a generalized removal method of high-intensity NS signals, which can apply to other models of probability density functions (PDFs).

2. Methods

2.1 Generalized removal method of high-intensity non-speckle signals

Echo-envelope signals higher than the threshold amplitude were removed as high-intensity NS signals. In our previous study[1)], the threshold was determined to minimize a modeling error of the MRA model. However, this method assumes that the population of echo-envelope signals follows the MRA model. To develop a generalized NS removal method which can apply to other PDF models, we focused on the discontinuity of the PDF of high-intensity NS signals. This approach was firstly introduced in our previous study to reduce the computational capacity of minimization approach of the modeling error.[2)] In this approach, the threshold value for removing NS signals was determined as follows:

The PDF of speckle-like signals show a continuous distribution. However, the PDF of NS signals shows a discontinuous distribution in higher amplitude region as shown in **Fig. 1**, because the NS signals show higher intensity compared to the background speckle-like signals and the amount of NS signals is small. Therefore, the threshold value is set to the envelope amplitude at which the probability density first drops to zero when searching from low amplitude to high amplitude.

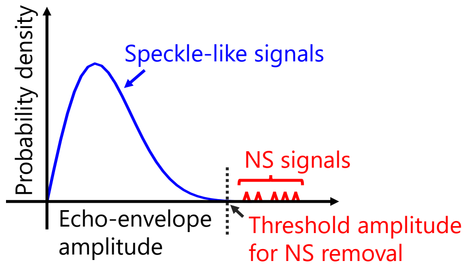

Fig. 1 Schematic of PDF properties of speckle-like signals and NS signals. NS: non-speckle.

In the previous study[2)], the applicability of this approach to the signals following the MRA model was examined. In this study, this approach was applied to signals following the Nakagami distribution model.

2.3 Nakagami distribution

The Nakagami distribution can evaluate tissue characteristics with low number density of scatterers whereas the MRA model can evaluate that with sufficiently high number density. The Nakagami distribution is given by

$$q_{\mathrm{NA}}(x|m,\Omega) = \frac{2m^m x^{2m-1}}{\Gamma(m)\Omega^m} \exp\left(-\frac{m}{\Omega}x^2\right), \quad (1)$$

where x is an echo-envelope amplitude and $\Gamma(\cdot)$ is a gamma function. m and Ω are called as Nakagami shape and scale parameters, respectively. The lower value of m $(0.5 < m < 1)$ expresses the condition of lower number density of scatterers.

2.3 Ultrasonic simulation

Field II[3,4)] was used to simulate the echo signals. A linear array probe with 128 elements was used to transmit and receive the ultrasound pulse waves. The distance between adjacent elements was set to 0.2 mm. The transmitted and sampling frequencies were set to 7.5 and 30 MHz, respectively. The compound imaging by plane wave with transmission angles from -10° to 10° at 5° intervals was used to acquire echo signals, and the delay-and-sum method was used for receive beamforming.

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To simulate Nakagami-like echo signals with lower number density of scatterers, point scatterers were randomly distributed to be that the number density becomes one point per -6 dB area of the ultrasonic point spread function (PSF). Then, to simulate high-intensity NS signals, point scatterers with 200 points per -6 dB area of the PSF were randomly distributed within a 0.3 mm diameter circular region with a depth of 20 mm. The region of interest (ROI) for the envelope statistics analysis was set to -5 to 5 mm in lateral direction and 15 to 25 mm in depth. The generalized NS removal method was applied to the envelope data in the ROI. Then, the Nakagami shape parameter m was estimated by the maximum likelihood estimation.

3. Results and Discussion

Fig. 2(a) shows the simulated ultrasound B-mode image without arranging the NS structure, and Figs. 2(b) and 2(c) show that with arranging the NS structure. In Fig. 2(c), the removed NS signals are shown by yellow. As shown in Fig. 2(b), the NS signals with higher amplitude are observed at the center of the image. These NS signals were correctly removed by the generalized NS removal method, as shown in Fig. 2(c).

Fig. 3 shows the estimated Nakagami shape parameter $\hat{m}$. Due to the existence of NS signals, $\hat{m}$ in (b) became lower compared with that without the NS structure in (a). This result indicated that the number density of scatterers was underestimated due to the existence of NS signals, resulting in the erroneous evaluation of tissue characteristics. However, in the result of (c) after removing NS signals, the similar values of m with (a) were obtained. Thus, it was confirmed that the tissue characteristics with Nakagami condition was correctly evaluated by applying the generalized NS removal method, even in the condition that NS signals exist.

4. Conclusion

This study examined the generalized NS removal method which can apply to various tissue characteristics. The examined NS removal method does not require information on the PDF model type that the echo signals follow. Therefore, the examined NS removal method may be applicable to various types of tissue characteristics, including the MRA condition examined in the previous study[2] and the Nakagami condition examined in this study.

Acknowledgment

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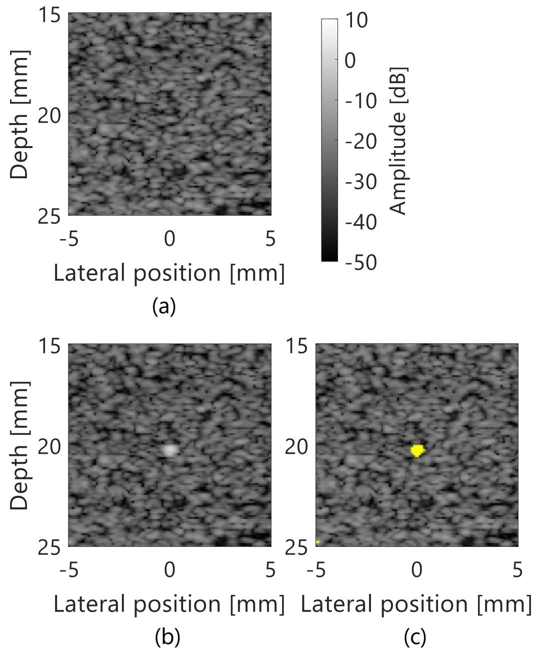

Fig. 2 Simulated ultrasound B-mode images (a) without arranging NS structure and (b, c) with arranging NS structure. In (c), removed NS signals are shown by yellow.

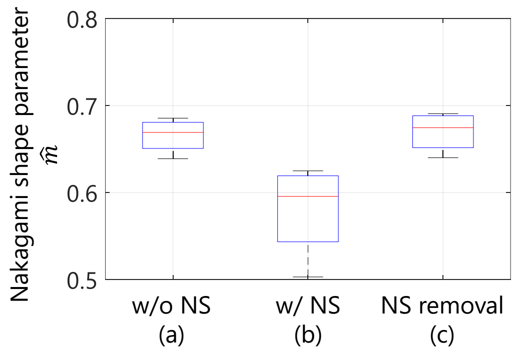

Fig. 3 Estimated Nakagami shape parameter $\hat{m}$ for simulated data (a) without arranging NS structure, (b) with arranging NS structure and before removing NS signals, and (c) with arranging NS structure and after removing NS signals. Results for 10 simulation data which were generated by randomly changing scatterer positions are plotted by boxplot. NS: non-speckle.

References

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