1Pb5-5

Verification of Relationship Between Accuracy of Multi-component Evaluation and Scatterer Structure in Amplitude Envelope Statistics

Tingzhen Zhang[1†], Yuki Ujihara[1], Shinnosuke Hirata[2], Kenji Yoshida[2], Tadashi Yamaguchi[2*], ([1]Grad. School. Sci. Eng., Chiba Univ.; [2]Center for Frontier Medical Engineering, Chiba Univ.)

1. Introduction

The amplitude envelope analysis plays a vital role in providing Quantitative Ultrasound (QUS) parameters to evaluate liver lesions. The relationships between the statistical parameters of the analysis models and liver fibrosis or hepatic steatosis grades were reported[1,2]. However, it is necessary to verify the independence of the liver's scatterer structure and echo signal components at based on the clinical ultrasound frequency range to achieve accurate characterization.

In this study, Double Nakagami (DN) model, which has been proposed as an evaluation model for hepatic steatosis, was applied to RF echo data from multi-component scatterer fields which was simulated by computer. The relationship between QUS parameters and the scatterer distribution structure was evaluated.

2. Simulation settings and methods

2.1 Computer simulation methods

The echo simulation was performed with Field II based on calculation of the spatial impulse response[3]. A single element concave transducer with a diameter of 10 mm, and a focus depth of 20 mm was simulated to transmit and receive of ultrasound. The center frequency and sampling frequency were 15 and 250 MHz, respectively. Besides, the point spread function of this transducer is 0.076 mm and 0.206 mm in depth direction and lateral direction, respectively. All the scatterers were placed in the simulation field which size was 3 mm × 3 mm × 6 mm in lateral, slice and depth direction (**Fig. 1**).

As shown in **Fig. 2(a)**, the scatterer was placed in the simulation field at 4 sc/psf to mimic a normal liver which has a homogeneous structure. High-scatterer-density parts orthogonal (**Fig. 2(b)**), parallel (**Fig. 2(c)**), and oblique (**Fig. 2(d)**) to the direction of sound wave propagation were created, and each was incorporated into the basic structure shown in **Fig. 2(a)**. The three strips of high-scatter-density parts have a thickness of 0.1 mm and a scatterer density of 36 sc/psf. These four computer scattering phantoms were used in the analysis.

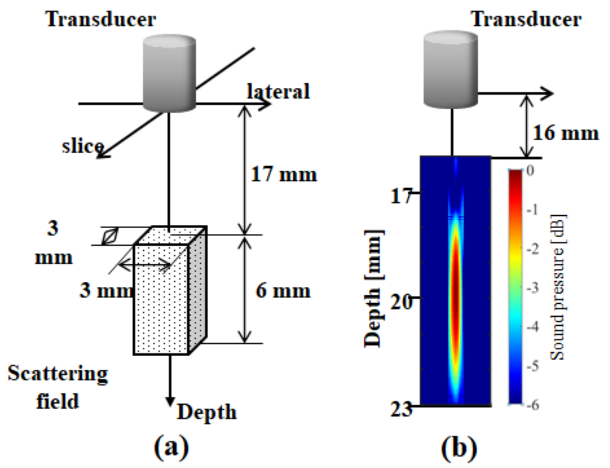

Fig. 1 Schematic image of simulation setup (a), and transmitted sound field of transducer (b).

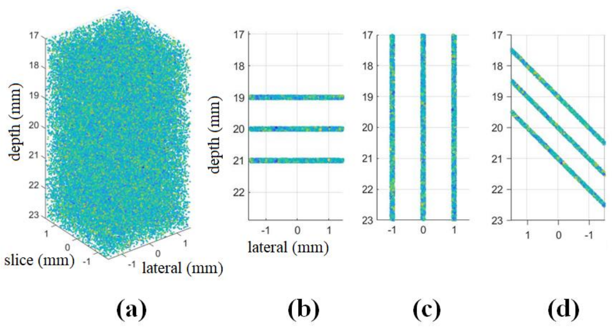

Fig. 2 Examples of scatterer structures, (a) homogeneous, (b) layer structure in orthogonal direction, (c) parallel direction, (d) oblique direction.

2.2 Amplitude envelope analysis

The relationship between the amplitude envelope probability density function (PDF) of the echo data and the one-component scatterer distribution can be approximated by the Nakagami model, given as,

$$p(x) = \frac{2\mu \cdot x^{2\mu-1}}{\Gamma(\mu) \cdot \omega^{\mu}} \exp\left\{-\frac{\mu x^2}{\omega}\right\} \qquad (1)$$

where x is amplitude envelope, Γ is the gamma function, ω is echo signal energy and μ is related

†zhangtz97@chiba-u.jp, *yamaguchi@faculty.chiba-u.jp

to the number density of scatterers. When the parameter $\mu = 1$, PDF approximates Rayleigh distribution.

DN model is composed of two Nakagami model to evaluate the statistical characteristics of echo signal from scatterers with different variance. It was given as,

$$p_{mix}(x) = (1-\alpha)p_L(x|\mu_L, \omega_L) + \alpha p_H(x|\mu_H, \omega_H) \quad (2)$$

In eq.2, p_* are Nakagami model from echo signal of each component, independently. And parameters μ_* represent number density of different components, $\alpha\omega_H$ is related to the echo signal energy of high variance component.

DN parameters were optimized using Nelder-Mead method based on the Kullback-Leibler (KL) divergence. By using "fminsearch" function in MATLAB (The Math Works Inc.), the combination of parameters that has the minimum KL divergence can be found, i.e., these parameters can describe the actual PDF most-similarity.

The analysis area was selected as the whole central slice of the scattering field. And a region of interest (ROI) was scanned on the scan-converted image. The size of ROI was set at five times the resolution cell (1.03 mm in lateral and slice, 0.38 mm in depth).

3. Result and discussion

Figure 3 shows **(a)** the B-mode images of each simulation echo data, **(b)** the B-mode images of a ROI, which was located in yellow area nearby the center of focus depth. The layer structure of orthogonal direction can be clearly represented on the B-mode image. In cases where the layers are oriented parallel or oblique, the visibility of the layers is reduced due to the relationship between the sound wave beam and the orientation of the scatterer.

Figure 4 shows the PDFs resulted from the evaluation of four different computer scattering phantoms (ROIs in **Fig. 3(b)**) with the DN model. In the homogeneous phantom shown in **Fig. 4(a)**, there is only one type of scatterer, so the PDF is also represented by DN_L only. In the orthogonal phantom shown in **Fig. 4(b)**, the high-scatterer-density region is dominant in the ROI, so the PDF of the synthesis is distorted, and it is clearly discriminated into two parts, DN_L and DN_H. The parallel phantom shown in **Fig. 4(c)** is difficult to visually identify the high scatterer density region, however, because of the large amount of scatterer near the center of the ROI, it can be confirmed that the elements of the echo signals that constitute DN_H and DN_L are present with equal frequency. The smaller difference in variance between the two PSFs compared to the orthogonal phantom is the result of mutual interference between the signals. The oblique phantom shown in **Fig. 4(d)** is also similar to the parallel case. However, this result is due to the fact that the ROI was set in the central scanline at the depth of focus, and the results will change for other scanlines due to the different content of the high-density scatterer region.

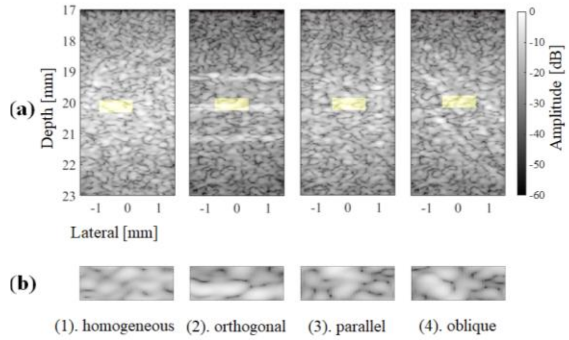

Fig. 3 B-mode images of four phantoms,
(a) full B-mode image, (b) ROI image for analysis.

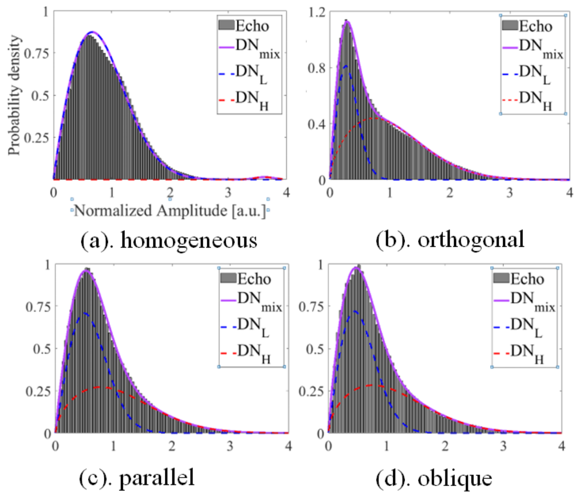

Fig. 4 Probability density function of echo signals in a ROI of four phantoms.

4. Conclusion

The amplitude envelope statistics by the DN model can distinguish the independent signal from different kinds of scatterers and evaluate tissues characteristic which is unclear in B-mode image. In future works, other influencing factors of scattering amplitude, e.g., scattering intensity and width of the sound beam will be assessed by computer simulation.

Acknowledgment

This work was partly supported by JSPS Core-to-Core Program JPJSCCA20170004, KAKENHI 19H04482, and the Institute for Advanced Academic Research at Chiba University.

References

1. K. Tamura et al.: Jpn. J. Appl. Phys. 57 (2018).
2. S. Mori et al.: Jpn. J. Appl. Phys. 57 (2018).
3. J. A. Jensen and N. B. Svendsen: IEEE Trans. Ultrason. Ferroelec. Freq. Contr. 39 (1992).