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Experimental analysis of estimation method of scatterer parameters in multi-Rayleigh model using contrast phantom
散乱体分布パラメータ推定のファントムを用いた実験的検討

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1. Introduction

We have been developing a quantitive diagnostic method of liver fibrosis using ultrasound images [1]. We proposed a multi-Rayleigh model which is a combination of Rayleigh distributions with different variances to express a probability density function (PDF) of a echo amplitude from liver fibrosis [2]. It is important to evaluate this method using clinical ultrasound images. However, it is hard to obtain the actual amout of fibrosis tissue using clinical data. In this study, we used ultrasound images of a contrast phantom of which acoustic parameters are known and evaluated the estimation accuracy of this method.

2. Multi-Rayleigh model

The PDF from homogeneous tissue with high scatter density, such as normal liver tissue, can be approximated by Rayleigh distribution given by

$$p(x) = \frac{2x}{\sigma^2}\exp(-\frac{x^2}{\sigma^2})$$

where x and σ are echo amplitude and scale parameter of distribution respectively. As the liver fibrosis progress and liver tissues become heterogeneous, the PDF deviates from Rayleigh distribution shown in **Fig. 1**. In this case, liver is composed of fibrotic tissue and normal tissue so we have proposed the multi-Rayleigh model with two components given by

$$p_{\mathrm{mix}}(x) = (1-\alpha)p_{\mathrm{L}}(x) + \alpha p_{\mathrm{H}}(x)$$

where $p_{\mathrm{L}}(x)$ and $p_{\mathrm{H}}(x)$ are Rayleigh distributions with low variance ($\sigma^2 = \sigma_L^2$, normal tissue) and high variance ($\sigma^2 = \sigma_H^2$, fibrotic tissue) respectively. α ($0 < \alpha < 1$) is the mixture rate of $p_H(x)$. α corresponds to the amount of fibrotic tissue, and variance ratio ($\sigma_{\mathrm{H}}^2/\sigma_{\mathrm{L}}^2$) corresponds to liver fibrosis stage.

The mixture rate and the variance ratio can be estimated using moments of echo amplitude. *n*-th order moment is given by

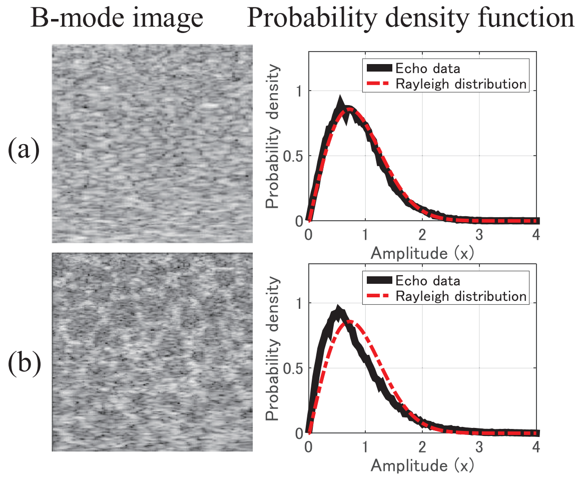

Fig. 1 B-mode images and probability density functions. (a) Normal liver, (b) liver fibrosis.

$$M_n = E[x^n]$$

where x is echo amplitude. Moments are shape parameters of PDF. We used 1st and 3rd moments to estimate the multi-Rayleigh model parameters.

3. Experimental method

We used a contrast phantom with multiple cylindrical areas brighter than the surrounding area shown in **Fig. 2**. In this study, we used two bright areas. The contrasts between the areas and background are + 5.6 dB and + 8.6 dB, respectively. As shown in **Fig. 3**, we regarded the low brightness background area as normal tissue and the high brightness area as fibrotic tissue. We set a region of interest (ROI) in the B-mode image. By moving ROI, the rate of high brightness area (fiber mixture rate) changed. The mixture rates were estimated from the RF data. We compared the results of experimental data and numerical simulation. In the numerical simulation, random numbers were generated using setting scatterer parameters.

4. Experimental result

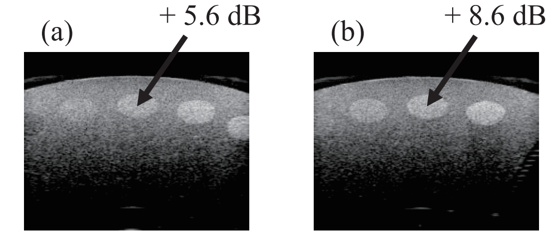

Fig. 2 B-mode images. Contrasts are (a) + 5.6 dB and (b) + 8.6 dB.

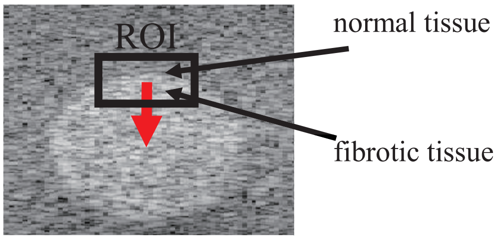

Fig. 3 Setting fiber mixture rate.

Fig.4 shows calculated first and third moments from the experimental data and numerical simulation. The horizontal axis is setting mixture rate and the vertical axis is calculated moments. The black dashed lines are theoretical values calculated from setting scatterer parameters. Both + 5.6 dB and + 8.6 dB results agree well with the theoretical values and variation of the calculated moments from experimental data is roughly same as that of numerical simulation.

Fig.5 shows the mixture rates estimated from the calculated moments. The horizontal axis is setting mixture rate and the vertical axis is estimated mixture rate. The black dashed lines are theoretical values calculated from setting scatterer parameters. Experimental data were compensated for transmission attenuation. Both + 5.6 dB and + 8.6 dB results agree well with the theoretical values. However, + 5.6 dB result had larger variation than + 8.6 dB result. This tendency can be seen in the experimental results and numerical simulation. On the other hand, the variation of the calculated moments of + 5.6 dB was roughly same as the results of + 8.6 dB. This result indicates moments of echo amplitude were calculated well regardless of the setting variance ratio but the estimated mixture rate had larger variation when the setting variance ratio became smaller. When variance ratio become smaller, the difference between p_L (Rayleigh distribution corresponds to normal tissue) and p_H (Rayleigh distribution corresponds to fibrotic tissue) become smaller. In this case, p_{mix} approaches Rayleigh distribution. The estimated multi-Rayleigh parameters become unstable when the PDF which is close to Rayleigh distribution is approximated by multi-Rayleigh model. This tendency can be seen in numerical simulation, too. It is found that in case of the variance ratio is small, the variation of the calculated moments cause the large variation of the estimated mixture rate.

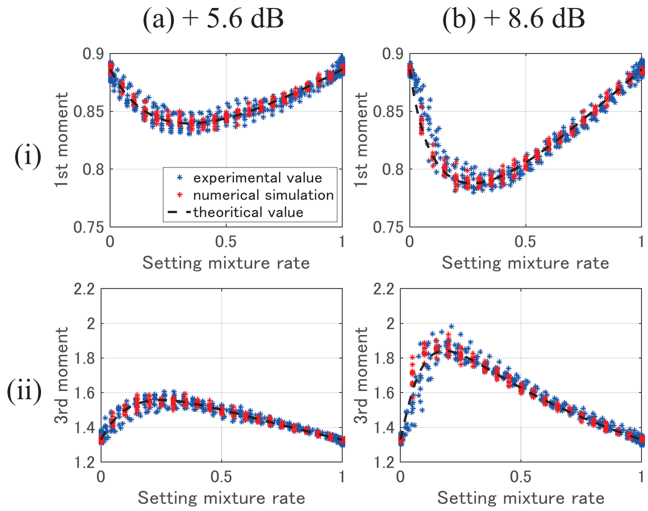

Fig. 4 (i) 1st moment and (ii) 3rd moment.
(a) + 5.6 dB and (b) + 8.6 dB.

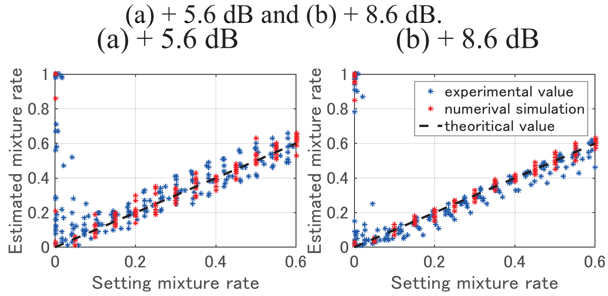

Fig. 5 Estimated fiber mixture rate.
(a) + 5.6 dB and (b) + 8.6 dB.

5. Conclusion

We evaluated the estimation accuracy of multi-Rayleigh parameters using the contrast phantom. The estimated mixture rates well corresponded to the theoretical values. When the variance ratio was small, the variation of the estimated mixture rate became large. In our future work, we will develop a stable estimation method when the variance ratio is small.

References

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