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Stability evaluation of estimation method of multi-Rayleigh model using simulated ultrasound B-mode image for liver fibrosis

肝病変の超音波シミュレーション画像を用いた
マルチレイリーモデル推定の安定性評価

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1. Introduction

A quantitative diagnostic method for liver fibrosis using an ultrasound B-mode image is highly required. We have focussed on a probability density function (PDF) of echo amplitudes from liver fibrosis. In our previous study, a quantitative evaluation method of liver fibrosis using a multi-Rayleigh distribution model, which is a combination model of several Rayleigh distributions with different variances, was proposed.[1~4] In this paper, a stability of the estimation method of the multi-Rayleigh model is evaluated using a simulated ultrasound B-mode image for liver fibrosis.

2. Multi-Rayleigh distribution model

In a homogeneous tissue, scattered points are distributed randomly and densely. An ultrasound B-mode image of the homogeneous tissue shows a speckled pattern and the PDF of echo amplitudes can be approximated by a Rayleigh distribution given by,

$$p(x) = \frac{2x}{\sigma^2}\exp\left(-\frac{x^2}{\sigma^2}\right), \quad (1)$$

where x is echo amplitude and σ is a scale parameter given by $\sigma^2 = E[x^2]$.

On the other hand, in an inhomogeneous tissue such as a tissue of liver fibrosis, the PDF of echo amplitudes deviate from the Rayleigh distribution. As a model of the PDF of echo amplitudes from liver fibrosis, a multi-Rayleigh model, which is a combination of Rayleigh distributions with different variances, was proposed.[1] Each Rayleigh distribution of the multi-Rayleigh model with three components expresses the hypoechoic, normal, and fibrotic tissues respectively. The multi-Rayleigh model with three components is given by,

$$p_{\mathrm{mix}}(x) = \alpha_{\mathrm{L}} p_{\mathrm{L}}(x) + \alpha_{\mathrm{M}} p_{\mathrm{M}}(x) + \alpha_{\mathrm{H}} p_{H}(x), \quad (2)$$

where α_{L}, α_{M}, α_{H} are mixture rates of Rayleigh distributions (p_{L}, p_{M}, p_{H}) with low, middle, high variances (σ_{L}^2, σ_{M}^2, σ_{H}^2), respectively. The variance ratios of each Rayleigh distribution, $\sigma_{\mathrm{M}}^2/\sigma_{\mathrm{L}}^2$, $\sigma_{\mathrm{H}}^2/\sigma_{\mathrm{M}}^2$ correspond to the hypoechoic and fibrotic progress ratios, respectively.

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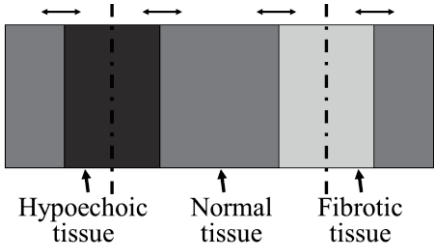

Fig. 1 Tissue model (10×30 mm^2) composed of hypoechoic, normal, and fibrotic tissues.

3. Stability evaluation of estimation method using simulated ultrasound B-mode image

A stability of estimation method of the multi-Rayleigh model was evaluated by using the simulated ultrasound image for liver fibrosis.

1.1. Scatterer distribution model

As a tissue model for liver fibrosis, a simple structural model composed of hypoechoic, normal, and fibrotic tissues arranged zonally, as shown in **Fig. 1**, was used. The mixture rates, which are parameters of the multi-Rayleigh model, can be set by changing the widths of hypoechoic and fibrotic tissues. In this tissue model, scattered points were distributed randomly and densely to express the scatterer distribution model of the liver tissue. By changing the reflection coefficients of scattered points, the variance ratios, which are parameters of the multi-Rayleigh model, can be changed.

In this paper, mixture rates of hypoechoic and fibrotic tissues were set from 0 to 0.4 at 0.1 interval, and variance ratios of hypoechoic and fibrotic tissues were set from 1.0 to 5.0 at 1.0 interval, independently. The examples of the scatterer distribution models are shown in **Fig. 2(i)**.

1.2. Ultrasonic simulation

Ultrasound B-mode images were simulated for

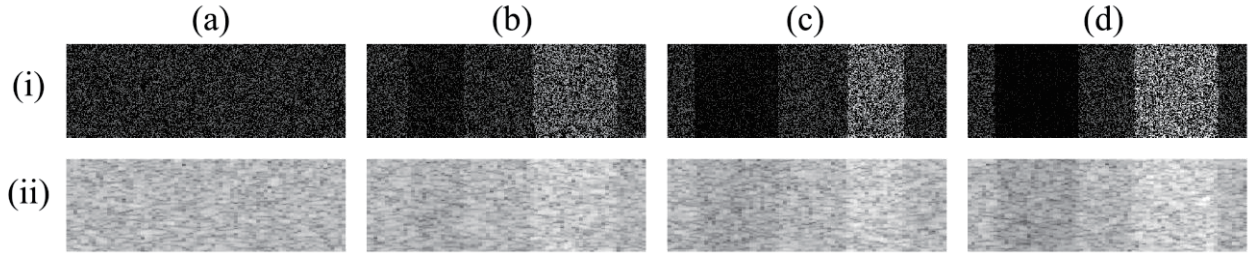

Fig. 2 (i) Scatterer distribution models and (ii) ultrasound B-mode images of (i). Setting parameters of models are (a) $\alpha_L = 0$, $\alpha_H = 0$, $\sigma_M^2/\sigma_L^2 = 1$, $\sigma_H^2/\sigma_M^2 = 1$, (b) $\alpha_L = 0.2$, $\alpha_H = 0.3$, $\sigma_M^2/\sigma_L^2 = 2$, $\sigma_H^2/\sigma_M^2 = 3$, (c) $\alpha_L = 0.3$, $\alpha_H = 0.2$, $\sigma_M^2/\sigma_L^2 = 3$, $\sigma_H^2/\sigma_M^2 = 4$, (d) $\alpha_L = 0.3$, $\alpha_H = 0.3$, $\sigma_M^2/\sigma_L^2 = 5$, $\sigma_H^2/\sigma_M^2 = 5$.

scatterer distribution models using Field II, which is a tool of an ultrasonic simulation. The scatterer distribution model was located 25 to 35 mm from the transducer. The center frequency and the sampling frequency were set to 5.0 MHz and 100 MHz. The focal position moves dynamically from 20 to 40 mm at 1.0 mm interval to control an ultrasonic beam width in an image. The ultrasound B-mode images simulated for scatterer distribution models (Fig. 2(i)) are shown in **Fig. 2(ii)**.

1.3. Estimation results of multi-Rayleigh model parameters

At each setting parameter, five B-mode images were simulated using five different patterns of randomly distributed scatters, and parameters of the multi-Rayleigh model were estimated from them respectively. Estimated results of mixture rates and variance ratios are shown in **Fig. 3** and **Fig. 4**. Estimated results were plotted using a boxplot. The outliers in the boxplot were removed. The black dashed lines show setting values in scatterer distribution models.

From the estimated results of multi-Rayleigh model parameters, it was found that,

- Setting mixture rates were 0 and/or setting variance ratios were 1.0: parameters could not be estimated accurately and estimation became unstable.
- Otherwise: estimated parameters well corresponded to setting parameters.

In the cases that estimation becomes unstable, the tissue models are composed of a single tissue which can be expressed by the single Rayleigh distribution, or, two tissues which can be expressed by the multi-Rayleigh model with two components. Therefore, the multi-Rayleigh model with three components have excessive parameters and estimation becomes unstable.

4. Conclusion

In this paper, the stability of the estimation method of the multi-Rayleigh model with three components were evaluated by using the simulated ultrasound B-mode image. From the estimated results of multi-Rayleigh model parameters, it is found that the estimation of parameters of the multi-Rayleigh model becomes unstable when the number of components of data is fewer than that of the multi-Rayleigh model. A development of a quantitative diagnostic method considering number of components of tissues is a future work.

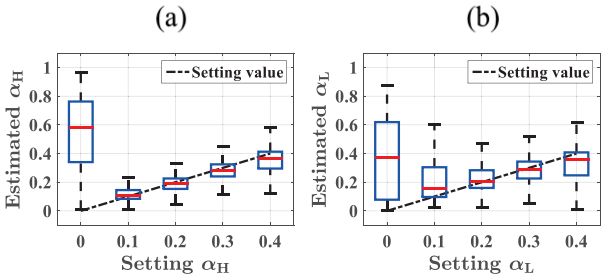

Fig. 3 Estimated results of mixture rates of (a) fibrotic and (b) hypoechoic tissues.

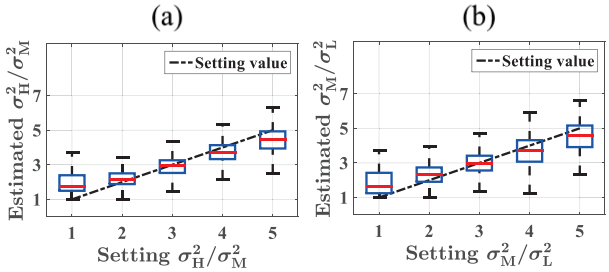

Fig. 4 Estimated results of variance ratios of (a) fibrotic and (b) hypoechoic tissues.

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