Quantitative evaluation of liver fibrosis using optimal input parameters for multi-Rayleigh model with two components

二成分マルチレイリーモデルの最適入力パラメータを用いた肝線維化の定量評価

Chuang ZHANG‡, Shinnosuke HIRATA, Hiroyuki HACHIYA (Tokyo Tech.)
張闖‡, 平田慎之介, 蜂屋弘之(東工大.)

1. Introduction

We have been developing a quantitative diagnostic method for liver fibrosis using an ultrasound B-mode image. In our previous study, we used the range of projection in the model parameters' space as the method to evaluate the estimation accuracy. The projection is the boundary of the area, which statistically, contains 95% of the data in the moments' space. But, since the slight deviation in the moment's space may cause large difference in the model parameters' space. So it is necessary to find the new evaluation method. In this report, we use the new evaluation method to examine the relationship between the combination of moments and the estimation accuracy of model parameters.

2. Evaluation method for liver fibrosis based on multi-Rayleigh model

2.1 Multi-Rayleigh model

When many scattered points are distributed randomly and homogeneously, such as in normal liver tissue, the PDF of the echo amplitude can be approximated by a Rayleigh distribution. The Rayleigh distribution is given by

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

where x and σ^2 are the echo amplitude and the variance of the echo amplitude, respectively.[1]

On the other hand, in an inhomogeneous medium, such as a fibrotic liver, the PDF of the echo amplitude deviates from the Rayleigh distribution. We proposed a multi-Rayleigh distribution model using a combination of Rayleigh distributions with different variances.

The multi-Rayleigh model with two components is given by

$$p_{\mathrm{mix2}}(x) = (1 - R_{\mathrm{m}})p_{\mathrm{low}}(x) + R_{\mathrm{m}}p_{\mathrm{high}}(x), \quad (2)$$

where $\mathrm{p_{low}}(x)$ is the Rayleigh distribution with a low variance(normal tissue), σ^2_{low}, and $\mathrm{p_{high}}(x)$ is the Rayleigh distribution with a high variance (fibrotic tissue), σ^2_{high}. R_{m} is mixture rate of Rayleigh distributions with high variances. By approximating the PDF of echo amplitudes using the multi-Rayleigh model, the fiber mixture rate R_{m}, and the fiber variance ratio $R_{\mathrm{v}} = \sigma^2_{\mathrm{high}}/\sigma^2_{\mathrm{low}}$, which is an indicator of the fibrosis progressive ratio can be estimated.

2.2 Estimation method of multi-Rayleigh model

In the evaluation of liver fibrosis based on multi-Rayleigh model, moments are the input parameters. Moments are indicators of the shape of the PDF. The n-th moment around average value, M_n, for normalized echo amplitudes is calculated as

$$M_n = E\left[\frac{(x-\mu)^n}{\sigma^n}\right], \quad (3)$$

where x is the echo amplitude. μ and σ are the average value and the standard variance of the echo amplitude, respectively. To estimate the multi-Rayleigh model parameters, moments of echo amplitudes are used as input parameters; therefore, the combination of moments used in the estimation algorithm affects the estimation accuracy of multi-Rayleigh model parameters. Thus, the selection of the optimal combination of moments is important to estimate the multi-Rayleigh model parameters stably.

3. The relationship between statistics of ultrasound echo envelope and the estimation accuracy of multi-Rayleigh model parameters

By using the ultrasonic simulation, the relationship between statistics of ultrasound echo envelope and the estimation accuracy of multi-Rayleigh model parameters is studied. As shown in **Figs. 1(a)** and **1(b)**, the B-mode image of normal and fibrotic tissues can be made by the change of reflection strength of the scatterer. Themixture rate and variance ratio are 0.3 and 3, respectively.[3]

Figure 2(a) shows the distribution of moments of echo amplitudes following the multi-Rayleigh model with the setting model parameters ($R_{\mathrm{m}} = 0.3, R_{\mathrm{v}} = 3$). This trial was iterated 1000 times. Then, the boundary of the area which statistically contains 95% of the data is shown in black. The black boundary is converted into the multi-Rayleigh model parameters' space as shown in **Fig. 2(b)**.

From the **Figures 2(b)**, we can see that the

‡E-mail address: zhang@us.sc.e.titech.ac.jp

estimation accuracy using the 1.5th and 0.65th in real and imaginary space is obviously worse than that in 1st and 3rd moments around zero when the projection of 95% boundary is used as evaluation method. But, enve if there is no sample point in the right upper area of the **Fig. 2(b)**, the boundary still contains the area. So, we directly use the standard deviation of sample points in model parameters' space to evaluate the estimation accuracy.

To determine the optimal combination of moments, the standard deviation for different combinations of real and imag, were calculated. The result are shown in **Fig. 3(c)**. The minimum value in **Fig. 3(c)** is marked with a circle.

4. Conclusions

In this paper, by using the simulated ultrasound B-mode image, the relationship between the input parameters for evaluation of liver fibrosis based on multi-Rayleigh model and the estimation accuracy of the multi-Rayleigh model parameters was examined by the new evaluation method in which the standard deviation of sample points in model parameters' space was used. From the simulation results, we can determine the moments which have high estimation accuracy by using the distribution area in the multi-Rayleigh model parameters' space.

References

1. T. Higuchi, *et al.*: Jpn. J. Appl. Phys., **52**, No. 7, pp. 07HF19-1-6, Jul. 2013.
2. T. Higuchi, *et al.*: Jpn. J. Appl. Phys., **53**, No. 7, pp. 07KF27-1-5, Jun. 2014.
3. C. Zhang, *et al.*: Jpn. J. Appl. Phys., **57**, No. 7, pp. 07LF27-1-7, Jun. 2018.

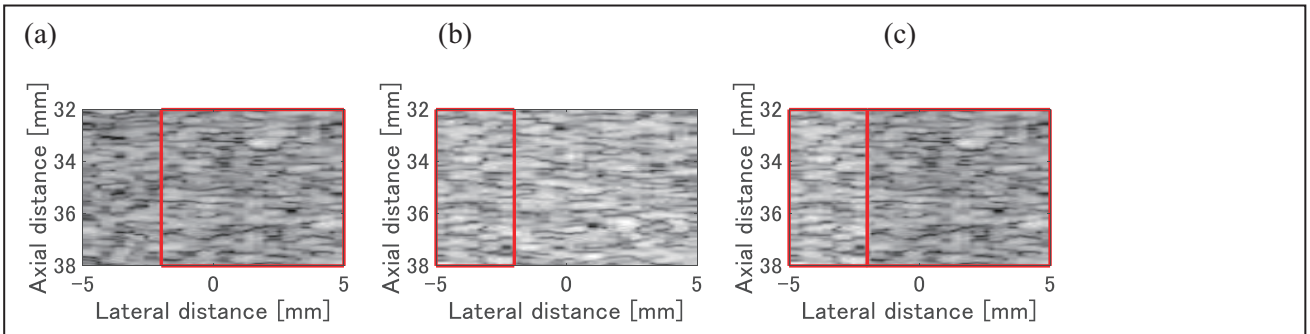

Fig. 1. (a) Normal tissue. (b) Fibrotic tissue. (c) Tissue model with multi-Rayleigh distribution.

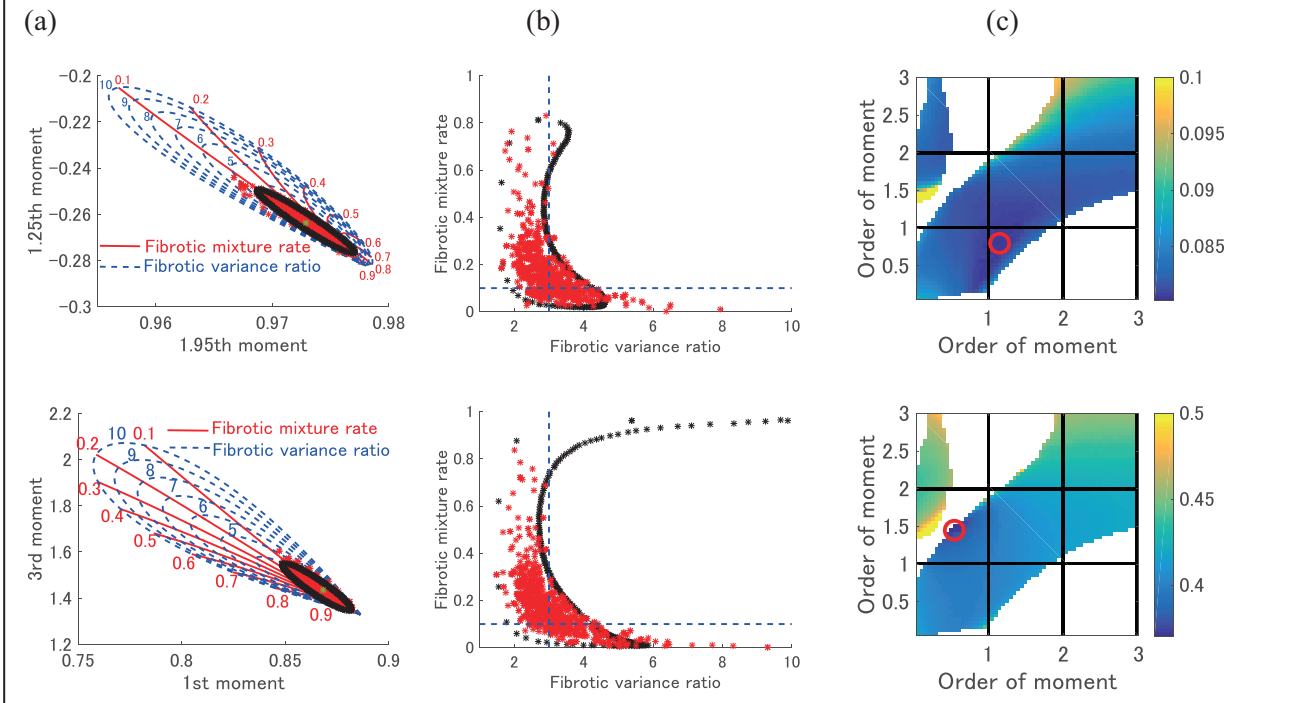

Fig. 2. (a) Moment map. (b) Projection of contour line using 1.55th and 0.65th moments in real and imaginary spaces. (i) 1.95th and1.25th in real and imaginary space. (ii) 1st and 3rd moments (around zero). (c)(i)Result of standard deviation of mixture rate. (c)(ii)Result of standard deviation of variance ratio. Setting model parameters ($R_{\mathrm{m}} = 0.3, R_{\mathrm{v}} = 3.0$).