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Evaluation of liver fibrosis using optimal moments as input parameters based on multi-Rayleigh model

マルチレイリーモデルに対する最適入力モーメントを用いた肝線維化推定の検討

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1. Introduction

We have been developing a quantitative estimation method of fibrotic liver diseases using multi-Rayleigh model. To improve the estimation accuracy of the estimation method, we have evaluated the optimal input moments in real space[1-3]. The main purpose of this study is to evaluate optimal input moments in complex spaces and an estimation characteristics of fibrosis 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].

We have 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 $p_{low}(x)$ and $p_{high}(x)$ are the Rayleigh distributions with a low variance σ_{low}^2 (normal tissue) and a high variance σ_{high}^2 (fibrotic tissue). R_{m} and R_{v} are mixture rate and the fiber variance ratio, $\sigma_{\mathrm{high}}^2/\sigma_{\mathrm{low}}^2$.

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. When n is not integer, moments calculated by using **Eq. (3)** are complex numbers. So, in this paper, we extend input moments to the combination of real and imaginary number to make the evaluation.

3. Evaluation of estimation accuracy of multi-Rayleigh model parameters result of simulation

To determine the optimal input parameters that have high estimation accuracy, the deviation of mixture rate and variance ratio with combinations of two moments (m_1, m_2), $U(R_{\mathrm{m}}, R_{\mathrm{v}}, m_1, m_2)$, are calculated. $U(R_{\mathrm{m}}, R_{\mathrm{v}}, m_1, m_2)$ is given by

$$U(R_m, R_v, m_1, m_2) = \frac{R_m - R_{m,min}(m_1,m_2)}{R_{m,max}(m_1,m_2) - R_{m,min}(m_1,m_2)} + \frac{R_v - R_{v,min}(m_1,m_2)}{R_{v,max}(m_1,m_2) - R_{v,min}(m_1,m_2)}, \quad (4)$$

where R_{m} and R_{v} are those of setting values, respectively. $R_{\mathrm{m,max}}$ and $R_{\mathrm{m,min}}$ are the maximum and minimum values of estimated mixture rate on the projected contour, respectively. $R_{\mathrm{v,max}}$ and $R_{\mathrm{v,min}}$ are the maximum and minimum values of estimated variance ratio, respectively. A small U value means a high estimation accuracy.[3] To determine the optimal combination of moments, $U(R_m, R_v, m_1, m_2)$ were calculated. The results are shown in **Fig. 1** when $R_{\mathrm{m}} = 0.3, R_{\mathrm{v}} = 3$. The minimum and maximum values of U in **Fig. 1** are marked with a circle and a cross, respectively.

Simulated B-mode images of normal and fibrotic tissues, as shown in **Figs. 2(a)** and **2(b)**, were used for simulation. **Figure 3** 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. 4.** We evaluate the optimal input moment using the same simulation with the mixture rate R_{m} that was set from 0.2 to 0.4 at 0.1 intervals and the variance ratio R_{v} that was set from 3 to 5 at 1 intervals. **Figure 5** shows the projection of contour line of the minimum values of U.

4. Conclusions

In this paper, we evaluated the optimal

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combination of moments in complex spaces. 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. We can also estimate the distribution of quantitative estimation results on model space.

References

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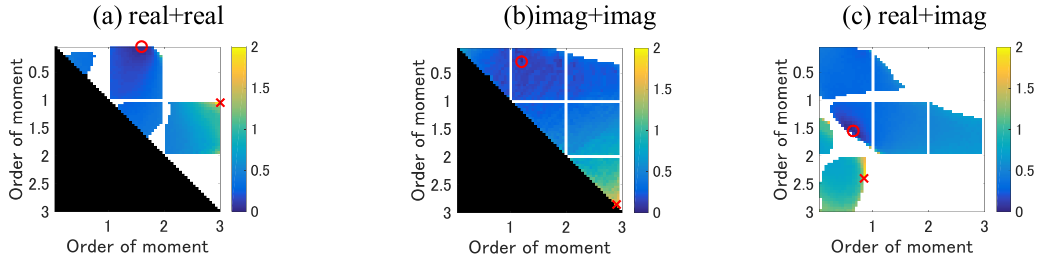
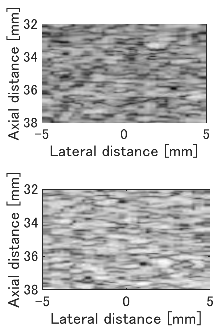
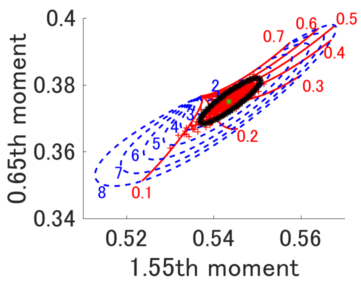


Fig. 1 Range of fibrotic parameters with setting model parameters. (a) Combination of real and real of moment. (b) Combination of imag and imag of moment. (c) Combination of real and imag of moment.





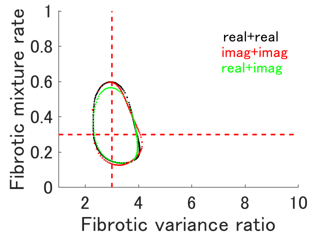


Fig. 2 (a) B-mode image of normal tissue. (b) B-mode image of fibrotic tissue.

Fig. 3 Moment map.

Fig. 4 Projection of contour line.

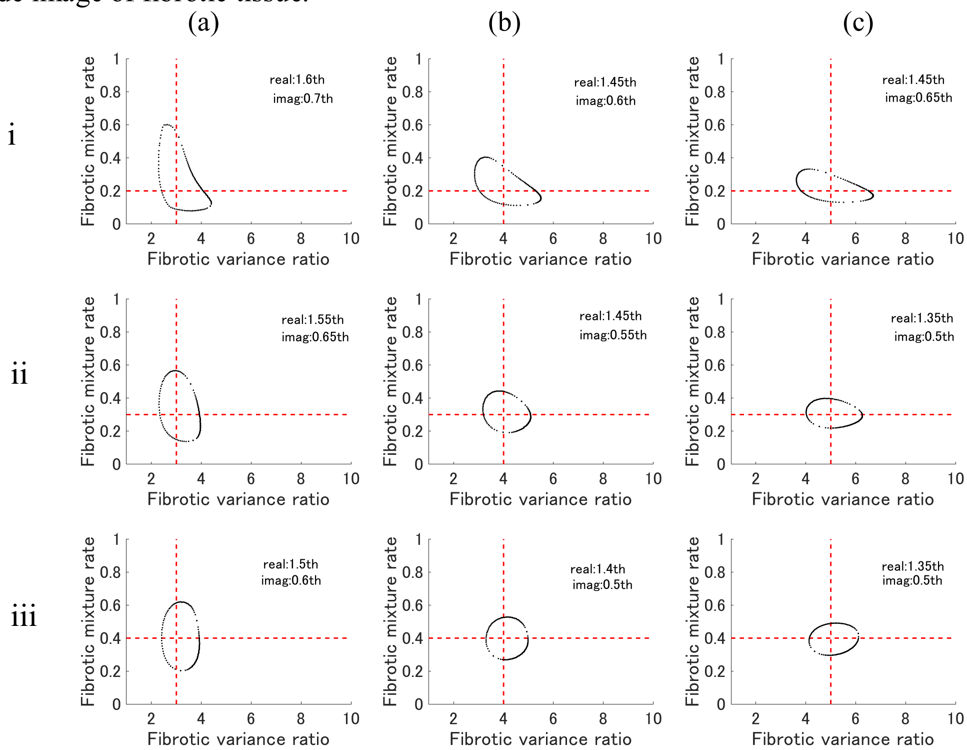


Fig. 5. Projection of contour line. The setting fibrotic parameters, $(R_{\mathrm{m}}, R_{\mathrm{v}})$, are (i~iii) $R_{\mathrm{m}} = 0.2, 0.3, 0.4$ and (a~c) $R_{\mathrm{v}} = 3.0, 4.0, 5.0$.