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Estimation algorithm of Multi-Rayleigh model parameters for quantitative diagnosis of liver disease
マルチレイリーモデルによる安定な肝炎線維化評価手法

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1. Introduction

We have been analyzing the probability density function (PDF) of echo amplitude in order to realize quantitative diagnosis of liver fibrosis. As a amplitude distribution model of the liver fibrosis, we have proposed Multi-Rayleigh Model expressed by the combination of Rayleigh distributions. Using two Rayleigh components that correspond to normal and fibrous tissue in a liver, we succeeded to evaluate the degeneration degree of liver quantitatively. However, the accuracy of approximation of the model to the data distribution becomes worse when a blood vessel is included in addition to the normal and fibrous tissue in the region of interest (ROI). In this paper, we examined the Multi-Rayleigh Model of three Rayleigh distributions to stabilize the quantitative evaluation of liver fibriosis in such a case. We evaluated accuracy of the approximation of the model to the clinical data quantitatively, and discussed a possibility of stable quantitative diagnosis method for liver fibrosis when low-intensity part is included in the ROI.

2. Amplitude distribution model of liver fibrosis

When a large number of scatterers are located randomly in the tissue such as normal liver, the PDF of echo amplitude can be approximated by Rayleigh distribution given by

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

where x, σ^2 is the echo amplitude and the variance of the echo amplitude, respectively.

As the liver fibrosis progresses, the amplitude distribution of echo signals deviates from the Rayleigh distribution. In this case, the liver is considered as heterogeneous medium which consists of normal and fibrous tissue, so we have proposed the model given by

$$p_{mix2}(x) = (1-\alpha)p_{low}(x) + \alpha p_{high}(x), \qquad (2)$$

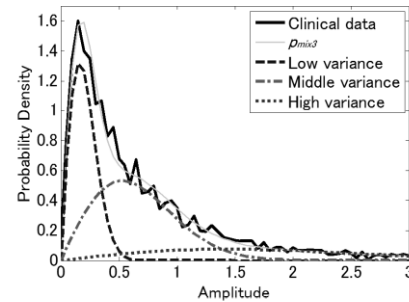E-mail address: hachiya@ctrl.titech.ac.jp

Fig. 1 Combination of three Rayleigh distributions and PDF calculated from the clinical data.

where p_{low} and p_{high} are Rayleigh distributions with low and high variances. Each Rayleigh distribution corresponds to the components of echo signal from normal and fibrous tissue. α $(0 \le \alpha \le 1)$ is the mixture rate of the Rayleigh distribution with high variance.

In order to consider low-intensity parts like blood vessel, Rayleigh distribution corresponding to low-intensity parts needs to be added to p_{mix2}. The model is given by

$$p_{mix3}(x) = \alpha_1 p_{low}(x) + \alpha_2 p_{mid}(x) + \alpha_3 p_{high}(x), (3)$$

where p_{low}, p_{mid} and p_{high} are Rayleigh distributions with low, middle and high variances respectively. Each Rayleigh distribution corresponds to low-intensity part, normal and fibrous tissue respectively. α_1, α_2 and α_3 are mixture rates of Rayleigh distribution with low, middle, and high variances, and satisfy the condition $\alpha_1 + \alpha_2 + \alpha_3 = 1$.

3. Evaluation using clinical data

3.1 Approximation accuracy of p_{mix3}

Fig. 1 shows the amplitude distribution when the ROI in the clinical data includes blood vessel. The distribution, p_{mix3}, is composed of three Rayleigh distributions. This model agrees well with clinical data.

The accuracy of approximation between data PDF and model can be evaluated by Kullback-Leibler (KL) divergence given by

$$D_{KL}(P \| Q) = \sum_x P(x) \log_e \frac{P(x)}{Q(x)}, \qquad (4)$$

where $P(x)$ and Q(x) are data and model probability distributions, respectively. When the two distributions $P(x)$ and $Q(x)$ are similar, D_{KL} is small.

To evaluate an accuracy of approximation of the model p_{mix3}, we analyzed clinical data shown in **Fig. 2(b)**. The data classified into F4 (liver cirrhosis) was used. The KL divergence was calculated by scanning small calculation area in an entire image. The size of calculation area was about 4.6 [mm] in depth and 9.1 [mm] in the lateral direction. **Fig. 3(a)** shows the KL divergence between clinical data and p_{mix2}. In Fig. 3(a), when the calculation area includes blood vessel, KL divergence increases and it means p_{mix2} is inadequate as a model in these area. **Fig. 3(b)** shows the KL divergence between data and p_{mix3}. The KL divergence is small in all the region of the image, and it means p_{mix3} can model the liver fibrosis including blood vessel adequately.

3.2 Quantitative diagnosis using p_{mix3}

We examined the fibrosis indices of Multi-Rayleigh Model calculated from the ROI located in **Fig. 2(a)** and **2(b)**. Both of the ROIs include low-intensity parts. **Fig. 2(a)** is classified into F2 (early hepatitis). The size of the ROI is about 9.46 [mm] in depth and 19.0 [mm] in lateral direction. A small calculation area which has the same size in section 3.1 was scanned within the ROI. **Fig. 4(a)** and **4(b)** show the fibrosis indices of p_{mix2} corresponding to F2 and F4 data respectively. The fibrosis indices are displayed by polar plot. The radius and the phase parameters correspond to the variance ratio ($\sigma_{high}/\sigma_{low}$, degeneration degree of fibrosis) and the mixture rate (α, amount of fibrous tissue). It is found that α is unstable in **Fig. 4(a)**, and $\sigma_{high}/\sigma_{low}$ is much bigger than expected value in **Fig. 4(b)**. It is considered as the effect of the low-intensity parts in the ROI. **Fig. 5(a)** and **5(b)** show the fibrosis indices of p_{mix3} corresponding to F2 and F4 respectively. The radius is variance ratio ($\sigma_{high} / (\sigma_{high}+\sigma_{mid})$), and the phase is mixture rate (α_3). It is found that α_3 is more stable than corresponding value α of p_{mix2} in **Fig. 5(a)**, and variance ratio $\sigma_{high} / (\sigma_{high}+\sigma_{mid})$ is more reasonable than $\sigma_{high}/\sigma_{low}$ in **Fig. 5(b)**. These results suggest that p_{mix3} can classify the echo signal components from low-intensity part, and estimate fibrosis indices stably.

4. Conclusion

We examined Multi-Rayleigh Model with three components to express the region including normal, fibrous tissue and blood vessel adequately. We showed quantitatively that p_{mix3} has high approximation accuracy in all the region of liver by KL divergence. And the fibrosis indices of p_{mix3} are more stable and reasonable than those of p_{mix2} when low-intensity parts are included in the ROI. We conclude that Multi-Rayleigh model with three components can classify the echo signal components from fibrous liver, and estimate fibrosis indices stably.

References
1. Y. Igarashi, H. Eduka, T.Yamaguchi, and H. Hachiya: Jpn. J. Appl. Phys. 49(2010), 07HF06.
2. Y. Igarashi, T. Yamaguchi, and H. Hachiya: Jpn. J. Appl. Phys. 50 (2011), 07HF17.
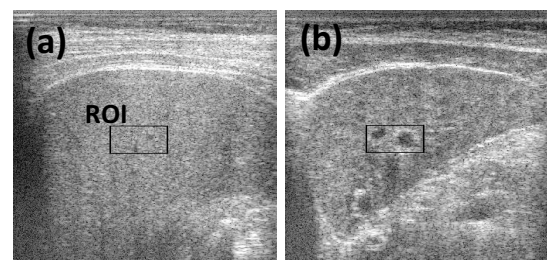3. T.Yamaguchi and H. Hachiya: J. Med. Ultrason. 37, (2010) 155.

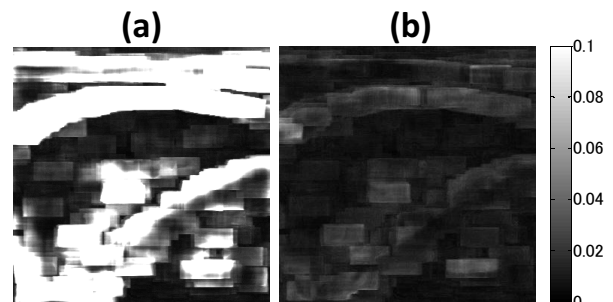Fig. 2 B-mode images of (a)F2 (b)F4 liver.

Fig. 3 KL divergences between clinical data (F4) and (a) p_{mix2} (b)p_{mix3}.
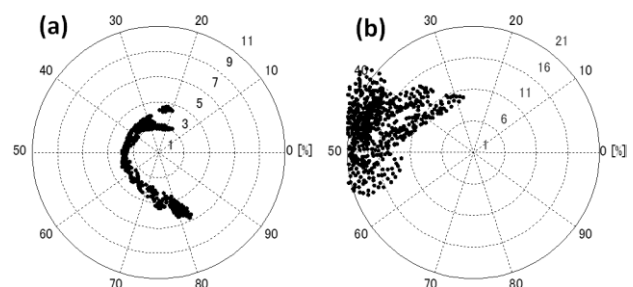

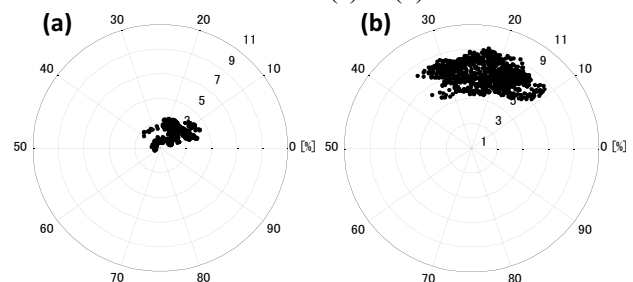Fig. 4 Polar plots of fibrosis indices of p_{mix2} calculated from (a)F2 (b)F4.

Fig. 5 Polar plots of fibrosis indices of p_{mix3} calculated from (a)F2 (b)F4.