Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 525-526
3-5 December, 2014

Quantitative analysis of ultrasonic images of fibrotic liver using co-occurrence matrix based on multi-Rayleigh model

マルチレイリーモデルを用いた肝炎超音波画像の同時生起行列の検討

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1. Introduction

Although ultrasonic diagnostic equipment is widely used as a non-invasive and real-time imaging modality for liver disease, its outcome is dependent on the skill of the doctor. Thus, quantitative diagnostic method based on ultrasonic echo signal is highly required. We have been analyzing co-occurrence matrices of ultrasonic images of fibrotic liver for quantitative tissue characterization[1]. In hepatitis or cirrhosis, texture of ultrasonic image with speckle pattern is cosidered to contain information on nodule and fibrotic tissue structure. In this report, we conducted texture analyis by using co-occurrence matrices generated from simulated B-mode images and examined quantitative relationship between texture feature of co-occurrence matrix and probability density function (PDF) of echo signal amplitude which can be expressed by multi-Rayleigh model.

2. Co-occurrence matrix and contrast

Co-occurrence matrix is one of the texture analysis methods. On an image f, a pair of pixels with coordinates (i, j) and (m, n) are given by distance r and angle θ between them as shown in **Fig.1(a)**. Probability of the pair of pixels whose amplitudes are a and b is defined by following eq.(1)

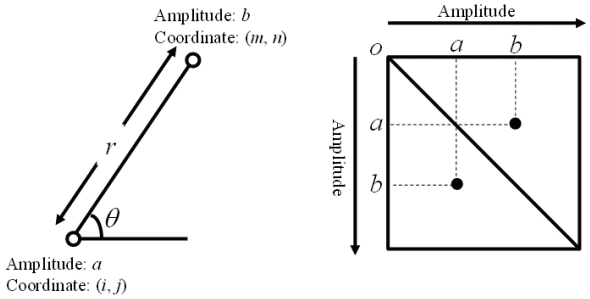
$$P(a,b;r,\theta) = P\{f(i,j) = a, f(m,n) = b\} \quad (1)$$

Given fixed positional parameters r and θ, co-occurrence matrix is generated and has the element of probability specified with amplitudes (a, b) of the pixel pair as shown in **Fig.1(b)**. Therefore this matrix is symmetry and its distribution aggregates on diagonal line in the case of uniform amplitudes of the image pixels while it spreads over the whole matrix in the case of wide-ranged amplitudes of the image pixels.

In this study, texture feature contrast defined by eq.(2) is used in order to quantify the distribution of co-occurrence matrix.

$$\mathrm{CNT}(r,\theta) = \sum_{a=0}^{n-1}\sum_{b=0}^{n-1}(a-b)^2 P(a,b;r,\theta) \quad (2)$$

Contrast value increases when the distribution spreads over the matrix.



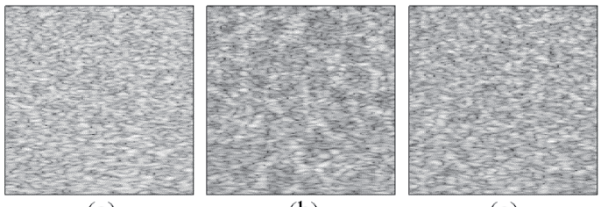
(a) Relative position of two pixels　　(b) Display method

Fig.1 How to make co-occurrence matrix

3. Method and Results

3.1 Simulated ultrasonic images of fibrotic liver

For quantitative analysis, simulated ultrasonic images generated with scatterer distribution model of fibrotic liver were used in this study. This model consists of normal tissue and fibrotic tissue with the scatterer density ratio set to 1:7, and the simulation images were created by Field II on MATLAB. In order to analyze the effect of structural size of liver tissue, non-fibrotic liver (normal tissue only) and 2 fibrotic liver models with different nodule size but the same fibrotic tissue rate (20%) were prepared for this study as shown in **Fig.2**.



(a)　(b)　(c)

Fig.2 simulated ultrasonic images of fibrotic liver (30 mm × 30 mm);
(a): Normal liver, (b): Fibrotic liver with large nodules, (c): Fibrotic liver with small nodules

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3.1 Estimation of contrast convergence value

When distance r becomes large enough against echo imaging resolution (Point Spread Function), the spatial correlation between a pair of pixels is lost and its probability can be described by $P(x)$, PDF of echo signal amplitude given by

$$P(a,b;r,\theta) = P(a)\cdot P(b) \quad (3)$$

In fibrotic liver, multi-Rayleigh model is proposed as an echo amplitude distribution model expressed by the combination of Rayleigh distributions as eq.(4)

$$P_{mix2}(x) = (1-\alpha)P_{low}(x) + \alpha P_{high}(x) \quad (4)$$

where P_{low} and P_{high} are Rayleigh distributions with low variance (normal tissue) and high variance (fibrotic tissue). α $(0 \le \alpha \le 1)$ is the mixture rate of the fibrotic tissue. This model shows good agreement with clinical data of fibrotic liver ultrasonic images[2]. We used this model and successfully quantified $P(x)$ of echo signal amplitude of simulated images used for co-occurrence matrix calculation as shown in **Fig.3**. Once the $P(x)$ is given, the convergence value of contrast at large distance r can be estimated by using eq.(2) and eq.(3).

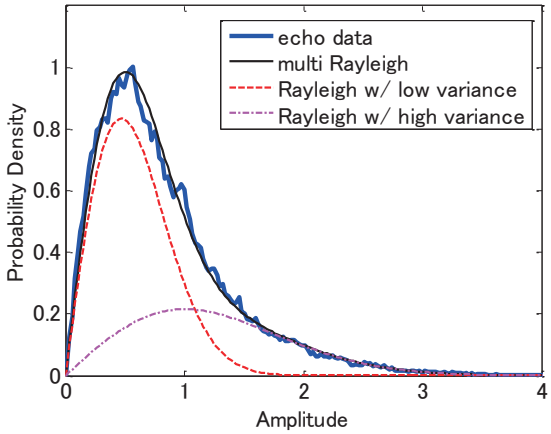

Fig.3 PDF calculated from simulated echo data and combination of two Rayleigh distributions

3.3 Texture analysis result

We examined co-occurrence matrices calculated from ultrasonic images of normal and fibrotic liver models as shown in Fig.2. Here, angle θ was fixed at zero (lateral direction), distance r varied from 0 to 25 mm, and 15 mm × 15 mm ROI was set as one of a pixel pair to calculate co-occurrence matrix. **Fig.4** shows calculated contrast values against distance r plotted with the convergence values estimated from PDF of echo signal amplitude. Contrast value starts from zero because $a = b$ at $r = 0$ for all pairs of pixels. As distance r increases, contrast value sharply rises and comes close to the estimated convergence value. Interestingly, the convergence value is larger for fibrotic liver model with large nodules (Fig.2 (b)) than that with small nodules (Fig.2 (c)) although both models have the same scatterer density ratio and fibrotic tissue rate. This can be explained by the averaging effect occurring within PSF, which leads to lower estimation of variance ratio and higher estimation of mixture rate as the size of the fiber region is closer to the size of echo imaging resolution[3].

In the range of r sufficiently larger than PSF, contrast converges with the estimated convergence value with fluctuation. This fluctuation is larger for fibrotic liver model with large nodules than the model with small nodules or normal liver model. We believe that this fluctuation derives from fibrotic structure and quantifying this fluctuation will give further quantitative information of fibrotic liver tissue.

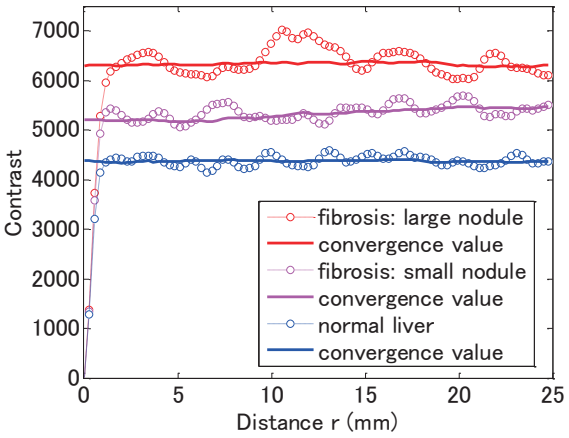

Fig.4 Contrast and estimated convergence value for 3 types of fibrosis liver models

4. Conclusion

We examined texture feature contrast calculated from co-occurrence matrices of simulated ultrasonic images for 3 different fibrotic liver models. Contrast value is found to converge with different values reflecting fibrotic tissue structure and its convergence value can be well estimated from the PDF of echo amplitude based on multi-Rayleigh model. For further study, we plan to analyze the fluctuation of contrast value in the range of large distance r which should reflect the structural information of the fibrotic liver tissue.

References

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