Constant False Alarm Rate Processing Based on Multi-Rayleigh Model for Extraction of Fibrotic Signals in Liver Fibrosis: A Preliminary Study

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***Abstract*—An extraction of fibrotic signals in fibrotic liver will contribute to diagnosis of liver fibrosis. As the fibrotic signals show higher variance of envelope amplitudes compared to that of norma tissue signals, the extraction of higher amplitude signals can extract a part of fibrotic signals. A constant false alarm rate (CFAR) processing is one of the thresholding methods to extract higher amplitude signals with quantitatively setting a threshold to be that the false alarm rate, that is, the false extraction probability of background signals, becomes constant. In a previous study, a Rayleigh based CFAR processing was proposed to extract the fibrotic signals because a probability density function (PDF) of normal liver tissue can be modeled by a Rayleigh distribution. However, in a progressive liver fibrosis, the PDF greatly deviates from the Rayleigh distribution; therefore, the PDF of background signals cannot be modeled by the Rayleigh distribution. In this study, we examined a multi-Rayleigh based CFAR processing. The multi-Rayleigh model is a PDF model for fibrotic liver and can extract the normal tissue component. Therefore, the threshold value was set to be that the false alarm rate of PDF of normal tissue component in the multi-Rayleigh model becomes constant. The *in vivo* data analysis showed that the multi-Rayleigh based CFAR processing increased the extracted rate of fibrotic signals for the liver fibrosis without increasing that for the non-fibrotic liver. Thus, the multi-Rayleigh based CFAR processing has a potential to improve the sensitivity of extraction of fibrotic signals, that will contribute to the higher-sensitivity detection of liver fibrosis.**

Keywords— liver fibrosis, envelope statistics, constant false alarm rate (CFAR), Rayleigh distribution, multi-Rayleigh model

I. Introduction

An envelope statistics analysis is effective for biological tissue characterization [1]. In the envelope statistics analysis for ultrasound signals, a property of a probability density function (PDF) of echo envelope amplitudes is evaluated. As the fibrotic signals show higher variance of envelope amplitudes compared to that of normal tissue signals, the extraction of higher amplitude signals can extract a part of fibrotic signals. A constant false alarm rate (CFAR) processing is one of the techniques to extract abnormal signals with higher amplitude by thresholding processing. In the CFAR processing, the threshold value is quantitatively determined to be that a false alarm rate, that is, a probability of false extraction of background signals, becomes constant.

Yamaguchi *et al.* [2] proposed an extraction method of fibrotic signals by a Rayleigh based CFAR processing because the PDF of envelope signals obtained from a normal liver tissue (liver parenchyma) can be modeled by a Rayleigh distribution. By the Rayleigh based CFAR processing, the fibrotic signals are quantitatively extracted to be that the false alarm rate of background signals following the Rayleigh distribution becomes constant.

However, in a case of progressive liver fibrosis, the PDF greatly deviates from the Rayleigh distribution. In this case, the PDF of background signals cannot be approximated by the Rayleigh distribution. Therefore, there is a possibility that the resultant false alarm rate of normal tissue signals does not become the set value, which may affect the extraction performance of fibrotic signals.

In this study, we examined a CFAR processing based on a multi-Rayleigh model. The multi-Rayleigh model is a model expressing the PDF of fibrotic liver signals by a combination of several Rayleigh distributions expressing hypoechoic, normal, and fibrotic tissues [3]. Based on the multi-Rayleigh model, the characteristics of liver fibrosis can be quantified [3]-[5].

As the PDF of normal tissue component can be estimated by the multi-Rayleigh model, in this study, the threshold value was set to be that the false alarm rate of signals following the PDF of normal tissue component becomes constant.

II. Methodology

A. Constant false alarm rate (CFAR) processing

In the CFAR processing, the threshold value T for extracting higher amplitude signals is determined to be that the false alarm rate P_{fa} becomes constant. The false alarm rate P_{fa} is defined by,

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$$P_{\mathrm{fa}} = \int_{T}^{\infty} p(r)dr\,, \tag{1}$$

where $p(r)$ is a PDF of background signals and r is a signal amplitude. In this study, signals higher than T was extracted as fibrotic signals.

B. Rayleigh based CFAR processing for fibrotic signals extraction [2]

A Rayleigh distribution $p_{\mathrm{RA}}(x)$ is defined by,

$$p_{\mathrm{RA}}(x|\sigma_{\mathrm{RA}}) = \frac{2x}{\sigma_{\mathrm{RA}}^2}\exp\left(-\frac{x^2}{\sigma_{\mathrm{RA}}^2}\right), \tag{2}$$

where x is an echo envelope amplitude and σ_{RA}^2 is called a scale parameter. In the Rayleigh based CFAR processing, the threshold value T is set to be that the false alarm rate of signals following $p_{\mathrm{RA}}(x|\sigma_{\mathrm{RA}})$ becomes constant.

C. Multi-Rayleigh based CFAR processing

A multi-Rayleigh model with three components is given by [3],

$$p_{\mathrm{MRA}}(x) = \alpha_{\mathrm{L}}p_{\mathrm{RA}}(x|\sigma_{\mathrm{L}}) + \alpha_{\mathrm{M}}p_{\mathrm{RA}}(x|\sigma_{\mathrm{M}}) + \alpha_{\mathrm{H}}p_{\mathrm{RA}}(x|\sigma_{\mathrm{H}}), \tag{3}$$

where $p_{\mathrm{RA}}(x|\sigma_{\mathrm{L}})$, $p_{\mathrm{RA}}(x|\sigma_{\mathrm{M}})$, and $p_{\mathrm{RA}}(x|\sigma_{\mathrm{H}})$ are Rayleigh distributions expressing hypoechoic, normal, and fibrotic tissues, respectively. α_{L}, α_{M}, and α_{H} are mixture rates of each component. As $\alpha_{\mathrm{M}}p_{\mathrm{RA}}(x|\sigma_{\mathrm{M}})$ corresponds to the PDF of normal liver tissue component, the threshold value T was determined to be that the false alarm rate of signals following $\alpha_{\mathrm{M}}p_{\mathrm{RA}}(x|\sigma_{\mathrm{M}})$ becomes constant in the multi-Rayleigh based CFAR processing.

D. In vivo data analysis

In this study, clinical data classified into F0 (non-fibrotic live), F1, F2, and F3, in accordance with liver biopsy, were analyzed. A new Inuyama classification was used as the classification of stage of liver fibrosis. All procedures of *in vivo* measurement were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later versions.

III. Results and Discussions

Fig. 1(a) shows B-mode images of liver classified into (i) F0 (non-fibrotic), (ii) F1, (iii) F2, and (iv) F3 (late stage of liver fibrosis). Figs. 1(b) and 1(c) show extracted results of fibrotic signals using the Rayleigh based CFAR processing and the multi-Rayleigh based CFAR processing, respectively. In Figs. 1(b) and 1(c), the extracted signals were plotted by yellow. The false alarm rate P_{fa} was set to 1%.

In the non-fibrotic liver, the extracted results showed a similar tendency between the Rayleigh based and multi-Rayleigh based CFAR processing as shown in Figs. 1(b)(i) and 1(c)(i). However, in the fibrotic liver shown in Figs. 1(ii)-1(iv), the multi-Rayleigh based CFAR processing increased the amount of extracted fibrotic signals compared to the Rayleigh based CFAR processing.

Fig. 2 shows the extracted rates of fibrotic signals using the Rayleigh based CFAR processing (blue) and the multi-Rayleigh based CFAR processing (red). As shown in Fig. 2, the multi-Rayleigh based CFAR processing increased the extracted rate of fibrotic signals for the liver fibrosis (≥F1), compared to the Rayleigh based CFAR processing.

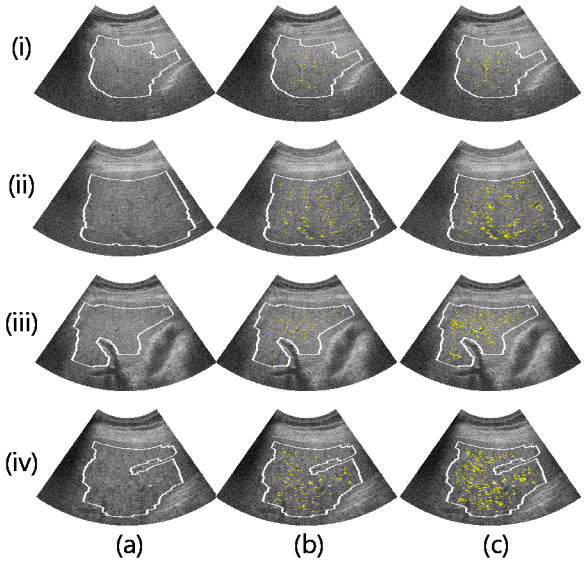

Fig.1 (a) B-mode images of liver with (i) F0 (non-fibrotic), (ii) F1, (iii) F2, and (iv) F3, respectively. (b) Extracted fibrotic signals (yellow pixels) using the Rayleigh based CFAR processing. (c) Extracted fibrotic signals (yellow pixels) using the multi-Rayleigh based CFAR processing.

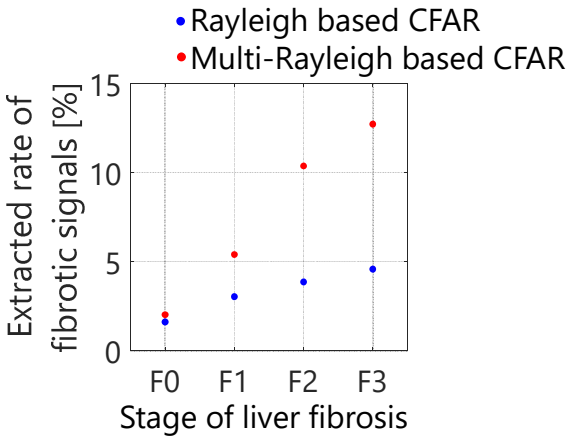

Fig. 2 Extracted rates of fibrotic signals using the Rayleigh based CFAR processing (blue) and the multi-Rayleigh based CFAR processing (red).

However, both methods showed similar extracted rates for the non-fibrotic liver (F0). This is because the multi-Rayleigh model equals to the Rayleigh distribution when only normal tissues are included in the analysis window. Therefore, when analyzing the non-fibrotic liver (F0), the threshold values determined by the Rayleigh based and multi-Rayleigh based CFAR processing tended to take similar values.

IV. Conclusion

In this study, the CFAR processing was examined to extract fibrotic signals in the fibrotic liver. The multi-Rayleigh

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based CFAR processing was compared to the conventional Rayleigh based CFAR processing. The multi-Rayleigh based CFAR processing showed the potential to improve the sensitivity of fibrotic signals extraction, compared to the conventional Rayleigh-based CFAR processing.

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