Use of Nakagami Distribution and Logarithmic Compression in Ultrasonic Tissue Characterization

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Abstract

Our previous simulation study showed that the Nakagami parameter estimated using ultrasonic backscattered envelopes compressed by logarithmic computation, denoted by $m_{\log}$, is more sensitive than the original Nakagami parameter m calculated using uncompressed envelopes for detecting the variation of scatterer concentration in tissues. This study made measurements on phantoms in order to further verify the performance of $m_{\log}$ in quantifying the properties of biological tissues. The ultrasonic backscattered signals from phantoms with different scatterer concentrations were acquired using 5 MHz focused and non-focused transducers. The Hilbert transform and logarithmic compression were in turn applied to the backscattered signals to obtain the uncompressed and compressed envelopes for estimating m and $m_{\log}$. The experimental results showed that, for both focused and non-focused transducers, the $m_{\log}$ parameter is indeed more sensitive than the m parameter in differentiating various scatterer concentrations. This may assist in the classification of scatterer properties using the Nakagami statistical model.

Keywords: Nakagami model, Ultrasonic backscattering, Logarithmic compression

Introduction

The Nakagami statistical model, which was initially proposed to describe the statistics of returned radar echoes, has subsequently been extensively applied for tissue characterization by ultrasound [1]. Using this distribution, it is both more general and simpler to model the probability density function (PDF) of the envelope of ultrasonic signals from tissues than other statistical models. The PDF of the Nakagami distribution *f(r)* calculated from the backscattered envelopes R is given by

$$f(r)=\frac{2m^m r^{2m-1}}{\Gamma(m)\Omega^m}e^{(-\frac{m}{\Omega}r^2)}U(r), \quad (1)$$

where $\Gamma(\cdot)$ and $U(\cdot)$ are the gamma and unit-step functions, respectively. Two of the parameters, the Nakagami parameter m and the scaling parameter Ω, can be calculated using

$$m=\frac{[E(R^2)]^2}{E[R^2-E(R^2)]^2} \quad (2)$$

and

$$\Omega=E(R^2), \quad (3)$$

where $E(\cdot)$ is the statistical mean. The m parameter is particularly useful for characterizing the probability distributions of ultrasonic backscattered envelopes, including the statistical conditions for pre-Raleigh, Rayleigh, and post-Rayleigh distributions. When the resolution cell of the ultrasonic transducer contains a large number of randomly distributed scatterers, the envelope statistics of the ultrasonic backscattered signals obeys the Rayleigh distribution. If the resolution cell contains the scatterers that have randomly varying scattering cross sections with a comparatively high degree of variance, the envelope statistics are pre-Rayleigh distributions. As the resolution cell contains the periodically located scatterers in addition to the randomly distributed scatterers, the envelope statistics are post-Rayleigh distributions. Because the values of m ranging from 0 to 1 reflect statistics ranging from pre-Rayleigh to Rayleigh distributions, and that those higher than 1 correspond to post-Rayleigh PDFs, thus the Nakagami parameter can be used to classify the properties of tissues. This has been validated in computer simulations [1,2], experiments on phantoms [1,2], and clinical measurements [3].

In order to better characterize tissues using the Nakagami parameter, some factors that may affect its estimation, such as the pulse length, beam width, attenuation, and background noise, have been explored and discussed [2,4]. Moreover, the effect of the nonlinear logarithmic compression, which is routinely used in existing ultrasonic scanners to adjust the dynamic range of envelope image, on the estimation of Nakagami parameter has also been investigated using computer simulations [5]. The simulation results showed that

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