Quantitative Analysis of Noise Influence on the Detection of Scatterer Concentration by Nakagami Parameter

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Abstract

The Nakagami statistical parameter has been demonstrated to be capable of detecting the variation of scatterer concentration in a biological tissue. The accuracy and sensitivity of the Nakagami parameter would be varied by the quality of ultrasonic backscattered signals, which is further affected by noise interference. For this reason, the experimental measurements and two-dimensional computer simulations were carried out to explore the effect of noise on the estimation of the Nakagami parameter as a function of scatterer concentration. The noise of the practical measurement system was acquired and subsequently its probability density function (PDF) and the Nakagami parameter were calculated. The incorporated simulation study was performed to evaluate the performances of the Nakagami parameter estimated from ultrasonic backscattered signals associated with different levels of signal-to-noise ratio (SNR) by adding simulated white noises with 5 MHz ultrasonic echoes corresponding to different scatterer concentrations. The obtained results showed that the envelope of white noise follows the Rayleigh distribution discernible by the calculated Nakagami parameter close to unity. Moreover, the sensitivity of Nakagami parameter to differentiate different scatterer concentrations decreased gradually corresponding to the decrease of SNR of backscattered signals. The SNR of backscattered signals was further suggested to be at least higher than 11 dB to affirm a satisfactory performance of the Nakagami parameter for characterizing the properties of biological tissues.

Keywords: Ultrasonic tissue characterization, Nakagami parameter, White noise

Introduction

The Nakagami statistical model initially proposed to describe the statistics of returned radar echoes has been extensively applied to the ultrasound characterization of tissue [1]. Compared to other statistical models, this model is relatively general and simple for practical applications. Two of its associated parameters, the Nakagami parameter m and the scaling parameter O, have been demonstrated to be capable of quantitating the scatterer concentration in biological tissues [1]. The Nakagami and scaling parameters respectively can be calculated using

$$m = \frac{[E(R^2)]^2}{E[R^2 - E(R^2)]^2}, \quad (1)$$

and

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

where E(•) is the statistical mean and R represents the envelope of ultrasonic backscattered signals. The Nakagami parameter in particular is feasible to characterize the probability density function (PDF) of ultrasonic backscattered envelope, including the statistical conditions for pre-Rayleigh, Rayleigh, and post-Rayleigh distributions. Values of m ranging from 0 to 1 reflect various PDFs from pre-Rayleigh to Rayleigh distributions and those of higher than 1 correspond to the PDFs of post-Rayleigh or Rician distributions. Due to various arrangements of scatterers in a tissue may result different backscattered statistics, the Nakagami parameter was further applied to classify the properties of tissues [2,3]. For better quantitating tissues using the Nakagami parameter, some factors could affect its estimation, such as pulse length, beam width, and attenuation, were taken into account [4,5]. In addition, the quality of ultrasonic backscattered signals, which would be affected by noise contamination in the measurements, might also be another key factor to influence the accuracy and sensitivity of the Nakagami parameter, especially in high frequency applications.

In general, electrical noises according to their sources can be classified into external and internal noises. The sources of external noise are numerous and complex, which mainly originate from the environment and user operation such as electromagnetic fields, instrument switching, or personnel

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