UNBIASED ESTIMATION OF ATTENUATION OF SOFT BIOLOGICAL TISSUE USING THE MEAN POWER DIFFERENCE BETWEEN TWO ADJACENT ENVELOPE SAMPLES

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ABSTRACT

This paper presents a theoretical framework of a new time-domain method for estimating the slope of ultrasonic attenuation (β) in reflection. The proposed method has two main advantages: high accuracy and technical simplicity. This approach treats a one-dimension model of an ultrasonic Gaussian pulse propagating through an attenuating homogeneous medium. The model is described by the linear nonhomogeneous differential equation. Solving the equation, allows us to calculate an unbiased estimate of β without using a "split-spectrum" technique. The statistical analysis of the β estimation is based on a multiplicative model of B-scan echoes. Each A-line is presented as an amplitude-modulated waveform with a noise carrier. The origin of carrier is backscattering effects, while the tissue attenuation defines the primary envelope of echo sequence. To compute attenuation, we must estimate the mean power of the envelope samples. However, linear processing is not effective in the case of multiplicative noise. Log operation transforms raw data into the sum of particular logarithms, so that linear filtering theory can be successfully applied. In this paper, the variance of the estimate of β is determined. The obtained results are used to define the relationship between the bandwidth of the transmitted burst, the variance of β, and depth resolution.

1. INTRODUCTION

In recent years, the measurement of acoustic attenuation in reflection has become a broadly accepted method of tissue characterization. Most of the research has been focused on frequency domain; however, the investigation carried out by Kuc[1] has shown that an acceptable standard deviation for β estimation can be achieved only in the case of extremely poor spatial resolution.

The recently proposed methods for estimating β in reflection mostly use the time domain. Basically, these methods use the effect of logarithmic power decay with depth. He and Greenleaf[2] proposed to estimate β from the peaks of the echo envelope (the EP method). Later He[3] improved the EP method by using a split-spectrum technique. Jang, Song, and Park[4] presented a new time-domain approach that is based on finding the minimum difference between the entropies for two adjacent envelope samples (the ED method). A paper by Claesson and Salomonsson[5] treated acoustic attenuation measurements as an ordinary communication theory problem: to estimate an unknown signal in the presence of noise.

In general, time-domain methods are faster and use lower-complexity calculation algorithms than do frequency-domain methods. As previously reported,[2,4] time domain methods are essentially robust to the random nature of echo. However, all the advantages of the recently proposed time-domain methods can be achieved if the downshift of the echo spectrum center frequency f_c relative to transmitted f_0 can be neglected. In the case of wideband echoes, this assumption is not valid. To reduce a bias on the β estimate due to uncertain f_c, He applied split-spectrum postprocessing.[3] Similarly, the ED algorithm[4] includes the step of depth-dependent correction.

Unlike known time-domain methods, the approach proposed in this paper is based on real-time evaluation of the echo spectrum center frequency.

2. UNBIASED ESTIMATION

When a transmitted acoustic pulse is weakly focused, the backscattered mean power $\psi(x)$ of an echo returning from a field point at a distance x from transducer can be expressed as [2]