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Letters to the Editor-in-Chief

A RESPONSE TO: A CRITICAL REVIEW AND UNIFORMIZED REPRESENTATION OF STATISTICAL DISTRIBUTIONS MODELING THE ULTRASOUND ECHO ENVELOPE

To the Editor-in-Chief:

We read the review article by Destrempes and Cloutier (2010) with great interest. The article gives an excellent overview and analysis of the statistical distributions that have been proposed to model the first-order statistics of the amplitude of the echo envelope in ultrasound images. The authors also refer to our article on modeling of envelope statistics (Nillesen et al. 2008) and we like to make an observation. In their review, the authors decided to leave out of consideration the results of our article, as they chose to take into account only statistical distributions of the amplitude of the *unfiltered* envelope of the radio-frequency (RF) image.

As stated by Destrempes and Cloutier (2010), we applied a filter to the RF data before computing the envelope. The data were band-passed filtered (2–3.6 MHz [–6 dB bandwidth]) using a linear phase finite impulse response (FIR) least squares filter to prevent disturbance by clutter and noise from frequencies outside the frequency band of the transducer. These frequency components may severely affect the envelope statistics. This filter does not modify the shape of the RF signal, nor of the envelope of it in the used frequency band. In the review by Destrempes and Cloutier, in most of the experimental studies cited by these authors, some kind of filtering of the envelope signal was applied either after quadrature demodulation (Shankar et al. 1993, 2000, 2001a, 2001b, 2003); after rectification of the RF signal (Wagner et al. 1983, 1987); or even the B-mode data from a commercial scanner were used with all the signal shaping and cosmetic operations involved (Dutt and Greenleaf 1996; Eltoft 2006). Only in two references in the article no processing after RF acquisition was mentioned (Insana et al 1986; Tsui et al. 2008), although this does not preclude that some filtering was applied.

We therefore suggest that in future studies linear phase bandpass filtering is acknowledged as a required standard procedure and not considered as an operation that (negatively) affects the RF-signal and derived envelope signal. Consequently, the results of our article and, in particular, the gamma distribution, should have been considered in this review, as the envelope data we used in our analysis do not essentially differ from the data obtained without filtering.

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RESPONSE TO THE LETTER TO THE EDITOR-IN-CHIEF ON MANUSCRIPT ENTITLED: "A CRITICAL REVIEW AND UNIFORMIZED REPRESENTATION OF STATISTICAL DISTRIBUTIONS MODELING THE ULTRASOUND ECHO ENVELOPE"

To the Editor-in-Chief:

We would like to thank the authors from Radboud University and Eindhoven University of Technology for their interest in our manuscript. In response, we consider three points and hope that this will clarify our main motivation in writing this review article.

POINT NUMBER 1

As stated in the Letter to the Editor, we decided to not consider the results of Nillesen et al. (2008), as we chose to take into account only statistical distributions of the amplitude of the unfiltered envelope of the radio-frequency (RF) image. We apologize for the confusion and we agree that linear band pass filtering of the RF signal is a standard process applied on any scanner. However, we meant the additional processing of RF signals or echo envelopes performed to obtain B-mode images. Most processing methods are not linear and involve image compression. We agree with Nillesen et al. that band pass filtering is standard in ultrasound imaging but one should recognize that the bandwidth of received RF echoes, and by extension band pass linear filtering, can affect speckle statistics. We refer readers to Cloutier et al. (2004) where it was shown that the frequency (mean frequency and associated bandwidth) of RF backscattered signals modified the estimated Nakagami parameters of speckle envelopes. As another example, the effect of the transducer frequency on the scatterer clustering parameter of the homodyned K-distribution was studied in Dutt and Greenleaf (1994). This is another reason for reinforcing the importance of specifying the bandwidth of received RF echoes in studies on envelope statistics. The processing methods to produce B-mode images from RF signals, including linear filtering, should be provided in published articles on envelope statistics.

We also wish to clarify our review inclusion criterion based on the order filtering was applied and to add a few precisions on Nillesen et al.'s interpretation of reported articles in their letter. In Shankar (2000), a (presumably linear) band pass filter was applied on RF signals before quadrature demodulation in the case of simulations (see Fig. 4 on page 732) and a similar processing was used in the case of real data (page 734). As cited by the authors, the same filtering was used for simulated and real data in Shankar (2001), and for real data in Shankar et al. (2001). The short correspondence manuscript by Shankar (2003) relied on random number simulations, whereas in Shankar et al. (1993), there is no mention of a filter applied after quadrature demodulation. In this last study, B-mode images were treated and reconstructed from a modified Doppler scanner. Also, Dutt and Greenleaf (1996) studied a model for the statistics of the log-compressed echo envelope. Therefore, it is understandable that log-compressed images were used in their tests and we mentioned that article in our review (Destrempes and Cloutier 2010) as an example of a statistical model for the log-compressed echo envelope. Eltoft (2005) presented a model for non-Rayleigh amplitude statistics and it was mentioned on page 1729 that "… none of the images have been subject to preprocessing that would alter their locale statistics." So, we presumed that the statistical model was tested on uncompressed B-mode images and we included Eltoft (2005) as a model for the amplitude of the echo envelope. Finally, Wagner et al. (1983, 1987) were cited to introduce the concept of backscattering by independent random scatterers. Therefore, we defend the choice of articles as relevant within the scope of our review article (Destrempes and Cloutier 2010).

POINT NUMBER 2

In Nillesen et al. (2008), the envelope statistics were modeled with gamma distributions for the purpose of image segmentation. Papers on image segmentation were beyond the scope of our review [*e.g.*, we did not cite our own articles on image segmentation using mixtures of Rayleigh (Roy Cardinal et al. 2006, 2010) or Nakagami (Destrempes et al. 2009a, 2009b) statistical distributions]. Note that the gamma distribution had been previously introduced for generic B-mode scans in Tao et al. (2006). That paper was not mentioned in our review article for the same reasons as above and we preferred to cite Nillesen et al. (2008), rather than Tao et al. (2006), because the filter applied to the RF signal was mentioned explicitly in the former reference.

POINT NUMBER 3

We take this opportunity to emphasize the main objective of our published review article, which was to attempt to standardize the mathematical expressions describing statistics of "unfiltered" B-mode images for the purpose of tissue characterization. As presented in Table 2 of Destrempes and Cloutier (2010), Rice and Nakagami modulated distributions; gamma, inverse Gaussian and generalized inverse Gaussian modulating distributions; and modulated parameters were proposed as compound representations of the homodyned K-distribution, generalized K-distribution, Rician inverse Gaussian distribution, Nakagami-gamma distribution and Nakagami-generalized inverse Gaussian distribution. Among these general models, we explained why we recommend the homodyned K-distribution, based on the behavior of the mean intensity and of the signal-to-noise ratio of the intensity. For tissue characterization, the homodyned K-distribution is the preferred distribution because of its generality and consistency with the limit case of a vanishing diffuse signal. Compared with other distributions discussed in our review article, the homodyned K-distribution gives additional information on the coherent-to-diffuse signal power ratio and on scatterer clustering. On that matter, let us mention that the gamma and the Nakagami distributions (which have only two parameters) do not allow the modeling of the coherent-to-diffuse signal power ratio nor the scatterer clustering. Nevertheless, the Nakagami distribution typically is used in the context of tissue characterization, among the two-parameter distributions, because it is easy to estimate and viewed as an approximation of the homodyned K-distribution [see Shankar (2001), Tsui et al. (2008) and the review article of Noble (2010)].

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