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The parametric images of microbubbles and tissue mimicking phantoms based on the Nakagami parameters map

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Abstract

The ultrasonic B-mode imaging is an important clinical tool used to examine internal structures of biological tissue and contrast microbubbles. To overcome the drawbacks of conventional B-scans which cannot fully reflect the nature of the tissue, other imaging methods based on stochastic models are proposed. Among these models, the Nakagami statistical model was chosen, because it is more general and simpler to apply than other statistical models (Rayleigh and K models), to generate parametric images based on the Nakagami parameters.
Experiments were performed using a 2.5 MHz linear array connected to an open research platform. A commercially phantom was used to mimic tissue and microbubbles backscatters. For several regions of interest and for different microbubbles dilutions, the RF signals have been generated at 3 and 5 transmit cycles.
The Nakagami image can be combined with the use of the B-mode image simultaneously to visualize the tissue and the contrast microbubbles structures for a better medical diagnosis.
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1. Introduction

The ultrasound B-mode imaging system is a noninvasive tool frequently used to examine the tissue anatomy in the medical diagnosis. The gray-scales in the B-mode images are determined according to the strengths of the echoes

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resulting from the changes in acoustic impedance inside the tissue (Tsui and Chien (2007)). The B-mode imaging in the clinical diagnosis is affected by many factors, such as image processing, system settings, and user operations (Szabo (2004)). Some useful quantitative parameters have been applied to quantify the properties of the tissue and the microbubbles when used as contrast agents. Many researchers have used stochastic models to describe the probability density function (PDF) of the ultrasonic signals envelope backscattered by tissues, which are usually treated as random signals. The parameters of these distributions depend on some characteristics such as the density (number of scatterers within the transducer resolution cell) and the scattering amplitude related to the size of the scatterers. Among the commonly used distributions, we can quote Rayleigh distribution (square root of an exponential distribution), K-distribution (Jakeman and Pusey (1976)) (square root of the product of a Gamma distribution with an exponential distribution), and Nakagami distribution (square root of a Gamma distribution). Rayleigh model which is commonly used (Goodman (1984)), needs some conditions such as the presence of a large number of randomly located scatterers. Wagner classifies the other models according to their Signal to Noise Ratio (SNR) as compared with the SNR of Rayleigh distribution (Wagner et al. (1986)). The first class called pre-Rayleigh (SNR < 1.91) describes heterogeneous textures. The second, called Rayleigh (SNR=1.91), defines the homogenous texture class. The third corresponding to the periodic texture is the post-Rayleigh class (SNR > 1.91).

It has been shown that K-distribution constitutes a quite good model for pre-Rayleigh and Rayleigh textures (Reid et al. (1998), Shankar et al. (2000)). The two K-distribution parameters provide informations on the number of scatterers, the variation of the scattering amplitude and the average scattering amplitude. But they are not enough general to describe the statistics of the backscattered echo from range cells containing a periodic alignment of scatterers giving rise to post-Rayleigh distribution. Recently Nakagami statistical model, initially proposed to describe the statistics of radar echoes, has been considered to be able to quantitatively characterize biological tissues thanks to its two parameters, Nakagami parameter (m) and scaling parameter Ω (Shankar (2000)). In addition to the scattering amplitude and density, this model can take into account the regularity of the scatterers spacing (Cramblitt (1999)). Nakagami statistical model has less computational complexity than the other models and is enough general to describe a wide range of scattering conditions in medical ultrasound, including pre-Rayleigh, Rayleigh and post-Rayleigh distributions. Although the Nakagami distribution can fit well with the PDF of the ultrasonic envelope, a multiple statistical distribution may be more appropriate to model the envelope statistics, since the ultrasonic signals returned from the tissues may contain contributions from more than one mechanism (Tsui and Wang (2004)).

This study is aimed to develop an image based on the Nakagami parameter map to assist in the B-mode image for tissue and microbubbles characterization.

2. Statistical model: Nakagami distribution

The probability density function of the envelope R of backscattered signals can be described in terms of Nakagami distribution and, in this case, it is defined by (Shankar (2000)):

$$f(R) = \frac{2m^m R^{2m-1}}{\Gamma(m)\Omega^m} \exp\left(-\frac{m}{\Omega}R^2\right)U(R) \tag{1}$$

where $\Gamma(.)$ and $U(.)$ are the Gamma function and the Unit step function, respectively. Nakagami parameter (*m*) and scaling parameter (*Ω*) can be calculated as follows:

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

and

$$\Omega = E(R^2) \tag{3}$$

where $E(.)$ is the statistical mean. The scaling parameter refers to the average power of the backscattered envelope. Moreover, the Nakagami parameter is particularly useful for characterizing the probability distributions of ultrasonic backscattered envelopes, including the statistical conditions for pre-Rayleigh, Rayleigh, and post-Rayleigh distributions. When the resolution cell of the ultrasonic transducer contains a large number of randomly distributed scatterers, the envelop statistics of the ultrasonic backscattered signals obeys the Rayleigh distribution. If the resolution cell contains scatterers with randomly varying scattering cross sections having comparatively high degree of variance, the envelop statistics are pre-Rayleigh distributions. If the resolution cell contains periodically located scatterers in addition to randomly distributed scatterers, the envelop statistics are post-Rayleigh distributions. As the values of m ranging between 0 and 1 reflect statistics ranging from pre-Rayleigh to Rayleigh distributions and larger values correspond to the PDFs of post-Rayleigh or Rician distributions, thus the Nakagami parameter can be used to classify the properties of tissues. This has been validated in computer simulations on phantoms ((Shankar (2000)), (Tsui and Wang (2004)) and clinical measurements ((Shankar et al. (2001)),Tsui and Chien (2007)).

3. Experimental results on phantoms

In the present study, experiments were performed using a commercially available platform with 128 independent channels equipped with analog transmitters. A tissue mimicking phantom containing a 4 mm diameter tube was used to acquire the responses of both tissue mimicking phantom and SonoVue microbubbles flowing in the tube through a pump and a magnetic stirrer at a rate of 20 ml /min. Ultrasound images and corresponding RF signals were acquired using transmit signals of 3 and 5 cycles at 2.5 MHz and using different microbubble concentrations. The applied mechanical index was 0.19.

The statistical analysis was performed on several regions of interest (ROI) located at different positions inside the tissue and contrast regions. The corresponding RF echoes have been analyzed in order to evaluate the Nakagami parameter m and the scaling parameter Ω according to three filtering procedures: raw data, filtering around the transmitted center frequency (fundamental) and around twice the transmitted frequency (2nd harmonic).

We can quote that for 3 transmit cycles, the B-scan ultrasound images are better than those obtained for 5 transmit cycles, see Fig. 1.

In the present study, the filtering around the 2nd harmonic is used to exploit the non-linear effect of ultrasonic interactions with the tissue and the contrast microbubbles. The B-scan images obtained in this case offer a better contrast of microbubbles when compared with regions in tissue, see Fig. 1.

The average values of the Nakagami statistical parameters (m and Ω) were estimated for the various regions inside the studied phantom, for 3 transmit cycles and for the three procedures of the filtering. The corresponding ultrasound images are shown in Fig. 2 and Fig. 3.

The size of the region of interest determines the resolution of the ultrasound image based on the Nakagami parameters. When the size of the region of interest decreases, the resolution of the parametric image is better.

However, for a small sized region of interest we have less information on the backscattered envelope, which leads to an unstable estimation of the Nakagami parameters. Consequently, before the construction of the image based on these parameters, an optimal size of the region of interest must be determined to satisfy simultaneously the stable estimation of the Nakagami parameters as well as an acceptable resolution of the parametric image. In this study the used size of ROI is of 0.5mm^2.

The image based on the Nakagami parameters in the regions of interest can provide, at the same time, the global and the local backscattered statistic of the ultrasonic signals, this demonstrates that the parametric image has an excellent ability to detect concentrations of local diffusers. In addition, when compared to the B-scan image which is easily influenced by factors related to the system and the operator, the parametric image provides a relatively uniform result which does not depend on the system setting. Moreover, this imaging principle associated with the parametric image allows the extraction of low backscatter information which can be lost in the classical B-scan image.

4. Conclusion

The study carried out shows that the discrimination between microbubbles and biological tissues can be obtained

by B-scan or from the Nakagami parameters determined as well near the fundamental frequency as around the harmonic mode frequency.

The parametric image can potentially become a new tool of diagnosis which can be easily combined with the classic images B-scan to display the structures of tissues and microbubbles.

Experimental and clinical validation must be made before the parametric image based on the model of Nakagami can be used as a reliable clinical tool.
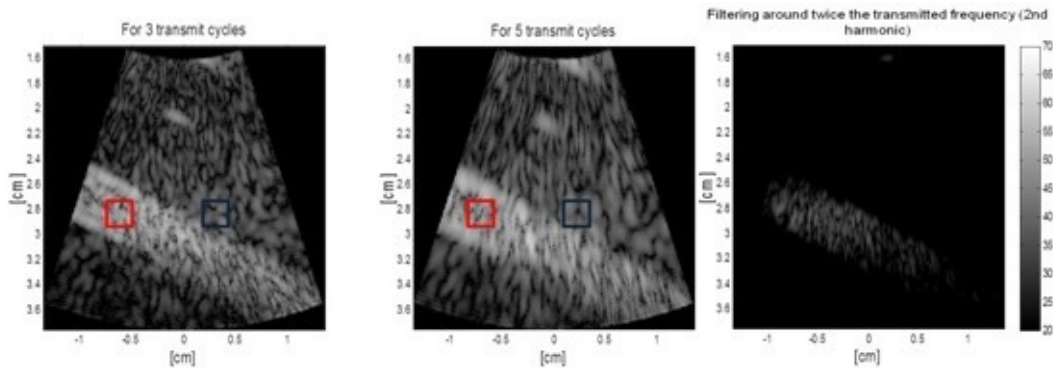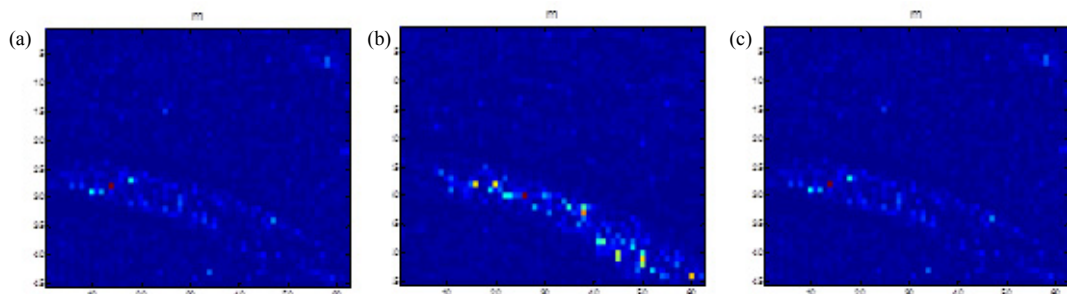

Fig. 1. B-mode images.

Fig. 2. Parametric images based on Nakagami parameter m: (a) Raw Echoes, (b) Echoes filtered around f_0,
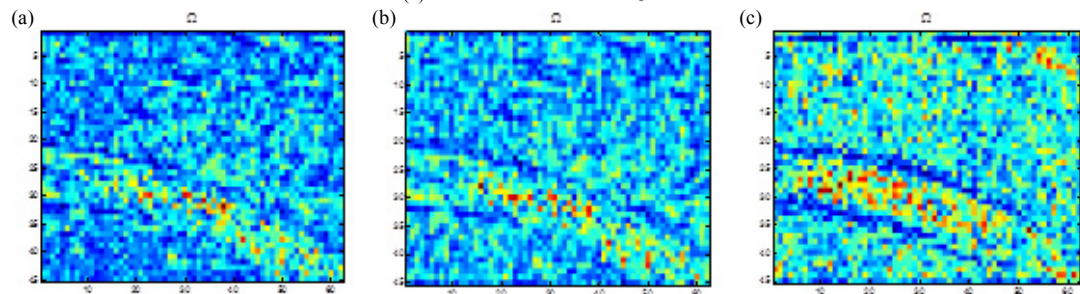(c) Echoes filtered around $2f_0$.

Fig. 3. Parametric images based on Nakagami parameter Ω : (a) Raw Echoes, (b) Echoes filtered around f_0,
(c) Echoes filtered around $2f_0$.

References

Cramblitt, R.M., Parker, K.J., 1999. Generation of non-Rayleigh speckle distribution using marked regularity models, IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, 46(4), 867-873.

Goodman, J.W., 1984. Statistical properties of laser speckle patterns, J.C. Dainty (Ed.), Laser Speckle and Related Phenomena, 2nd Edition, Springer, vol.9 of Topics in Applied Physics, Berlin.

Jakeman, E., Pusey, P. N., 1976. A model for non-Rayleigh sea echo, IEEE Trans On antennas and Prop 24(6), 806-814.

Reid, J.M., Forsberg, F., Halpern, E.J., Piccoli, C.W., Molthen, R.C., 1998. Comparisons of the Rayleigh and k-distribution models using in vivo breast and liver tissue, Ultrasound Med. Biol 24(1), 93-100.

Shankar, V. A., Dumane, J. M., Reid, V., Genis, F., Forsberg, C.W., Piccoli, Goldberg, B.B., 2000. Use of the k-distribution for classification of breast masses, Ultra. Med. Biol 26(9), 1503-1510.

Shankar, P.M., 2000. A general statistical model for ultrasonic backscattering from tissues, IEEE Trans. Ultrason Ferroelec Freq Contr 47, 727–736.

Shankar, P.M., Dumane, V.A., Reid, J.M., Genis, V., Forsberg, F., Piccoli, C.W., Goldberg, B.B., 2001. Classification of ultrasonic B-mode images of breast masses using Nakagami distribution, IEEE Trans. Ultrason Ferroelec Freq Contr 48, 569 –580.

Szabo, T. L., 2004. Diagnostic ultrasound imaging, MA: Elsevier Academic Press,Burlington.

Tsui, P.H., Wang, S.H.., 2004. The effect of the transducer characteristics on the estimation of Nakagami parameter as a function of scatterer concentration, Ultrasound Med Biol 30, 1345–1353.

Tsui, PH., Chien, CC., 2007. Imaging local scattered concentrations by the Nakagami statistical model, Ultrasound Med Biol 33, 608–619.

Wagner, R. F., Smith, S. W., Sandrik, J. M., Lopez, H., 1986.Statistics of speckle in ultrasound B-Scans, IEEE Trans. Sonics Ultrason 30, 156-163.