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# Ultrasonic Echosignal Applied to Human Skin Lesions Characterization

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The paper presents a classification of the healthy skin and the skin lesions (basal cell carcinoma) basing on a statistics of the envelope of ultrasonic echoes. The echoes envelopes distributions were modeled using Rayleigh and $K$-distribution. The distributions were compared with empirical data to find which of them better models the statistics of the echo-signal obtained from the human skin. The results indicated that the $K$-distribution provides a better fit.

Also, a characteristic parameter of the $K$-distribution, the effective number of scatterers ($M$), was investigated. The values of the $M$ parameter, obtained for the skin cancer (basal cell carcinoma), were lower as compared to those obtained for the healthy skin. The results indicate that the statistical quantitative ultrasound parameters have a potential for extracting information useful for characterization of the skin condition.

**Keywords:** statistics, $K$-distribution, Rayleigh distribution, ultrasonic scattering, human dermis.

## 1. Introduction

The ultrasonic echo-signal received by a transducer is formed from the summation of partial echoes scattered from the tissue inhomogeneities. Interference of waves reflected from randomly located scatterers results in formation of speckles, which can be modelled in ultrasonic images as a random process whose statistical features depend on the tissue properties. When the number of scatterers contained in the resolution cell and involved in the signal formation is high intensity of speckles (a signal envelope) is Rayleigh distributed. In the case when the number of scatterers is low the Rayleigh distribution is not applicable. In this situation, the envelopes of echoes from a tissue may be modelled in terms of a non-Rayleigh statistics.

Although examinations of a statistics of ultrasonic signals for their potential to classify types of tissues have been intensively studied (Molthen *et al.*, 1995; 1998), in the case of the skin tissue such studies have not been widely carried on. Raju and Srinivasan (2002) studied ultrasonic signals backscattered from a normal human dermis and subcutaneous fat *in vivo*. They found that the Generalized Gamma, $K$- and Weibull distributions modelled the envelope statistics well, while the Rayleigh distribution provided a poor fit. Raju *et al.* (2003) noted the necessity of a correction of diffraction during a statistical analysis of the echo-signal. They showed that diffraction affects the echo statistics parameters due to a variation in the beam size with the distance.

In this paper we have concentrated on the $K$-distribution which was analyzed to check whether it is suitable for modelling the statistics of the envelope of the signal obtained from the human dermis *in vivo*. Also, a classification of the healthy skin and the skin with the diagnosed basal cell carcinoma was analyzed using an effective number of scatterers given by the $M$ parameter of the $K$-distribution.

## 2. Statistics of the echo-envelope

Tissues can be modelled as a collection of small scatterers. Therefore, it can be assumed that the backscattered signal results from reflections from indi-

vidual scatterers in an isolated volume (resolution cell). The signal backscattered by each individual scatterer can be represented as a phasor (Goodman, 2007). The signal components may have both random lengths (amplitudes) and random directions (phases) in a complex plane. The echo-signal from the resolution cell can be described as:

$$s(t) = \mathrm{Re}\left\{Ae^{i\omega t}\right\}, \tag{1}$$

where $\mathrm{Re}\{.\}$ is the real part of the expression, $\omega$ is the transmission frequency, and $A$ is a complex amplitude of the echo-signal given by the expression (for $N$ scatterers in the resolution cell):

$$A = \sum_{k=1}^{N} A_k e^{j\varphi_k}. \tag{2}$$

In (2) $A_k$ and $\varphi_k$ are the amplitude and phase of the $k$-th scatterer echo. If the number of scatterers within the resolution cell is high ($N > 10$), then it follows from the central limit theorem that the signal can be modelled using a Gaussian distribution. It can also be shown that the envelope of the RF-signal is statistically described by the Rayleigh distribution with the probability density function (pdf) given by:

$$p(A) = \frac{A}{\sigma^2} e^{-A^2/2\sigma^2}, \tag{3}$$

where $A$ is the amplitude and $\sigma$depicts a scaling parameter.

As it was stated above, the Rayleigh statistics is considered when the high scatterers' density conditions exist (the model requires densities of 10 scatterers per resolution cell or higher (Molthen *et al.*, 1995)). However, in the case of skin tissues these conditions are not met, since the number of scatterers per resolution cell is not large enough and the scatterers might not be located randomly (due to the periodicity, clusterings, etc.). Therefore, it is necessary to apply a more flexible model than the Rayleigh distribution to be able to model the statistics of the envelope of the signal under varying conditions. The $K$-distribution whose probability density function is given by:

$$p(A) = 2\left(\frac{A}{2}\right)^{M} \frac{b^{M+1}}{\Gamma(M)} K_{M-1}(bA), \tag{4}$$

where $b = \sqrt{\dfrac{4M}{E[A^2]}}$ and $K_\beta(\cdot)$ is the modified Bessel function of the second kind of the order $\beta$, $\Gamma(\cdot)$ is the standard Gamma function, seems to be a good candidate.

Jakeman and Pusey (1976) have shown that the parameter $M$, which is called the "effective number of scatterers", can be viewed as the number of scatterers per resolution cell multiplied by a coefficient which describes the lack of homogeneity and variation of scattering cross-sections in the range of the resolution cell.

The parameter $M$ can be expressed in terms of the normalized even moments. The $\eta$-th central moment of the envelope $A$ for the $K$-distribution has the form:

$$E[A^\eta] = \left(\frac{E[A^2]}{M}\right)^{\eta/2} \frac{\Gamma\left(\frac{\eta}{2}+M\right)\Gamma\left(\frac{\eta}{2}+1\right)}{\Gamma(M)}. \tag{5}$$

For $\eta = 2$, $E[A^\eta] = E[A^2]$ and the normalized central moment for $\eta = 4$ is given by:

$$r_4 = \frac{E[A^4]}{[E[A^2]]^2} = 2\left(1 + \frac{1}{M}\right). \tag{6}$$

Thus,

$$M = \frac{2}{r_4 - 2} = \frac{2}{\dfrac{E[A^4]}{[E[A^2]]^2} - 2}. \tag{7}$$

The ability of this distribution to model a statistics of the signal under varying conditions was demonstrated in details by Jakeman and Tough (1987). In this work, it was shown that in the case when $M \to \infty$ the $K$-distribution is approaching the Rayleigh limit, and Eq. (4) can be expressed in the form:

$$P(A) = \left(\frac{2A}{E[A^2]}\right) e^{-A^2/E[A^2]}. \tag{8}$$

Figure 1 shows the probability density function of the $K$-distribution plotted for various values of the parameter $M$. It is easy to see that the $K$-distribution covers a range of distributions, approaching the Rayleigh distribution as $M$ becomes large, and becoming log normal as $M \to 0$. It is worth noting that the $K$-distribution tends to the Rayleigh distribution for the $M$ value much lower than infinity. Basing on the plots of the $K$-distribution (Fig. 1) it can be seen that the differences between the distribution for $M = 12$ and $M = 20$ are minor. In practice it can be concluded that the $K$-distribution is essentially Rayleigh for the value of the $M$ parameter greater than 10.

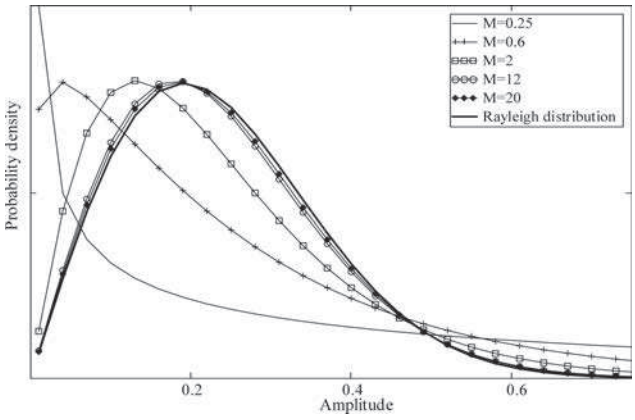



Fig. 1. Plots of the $K$-distribution pdf for various values of the effective number of scatterers.

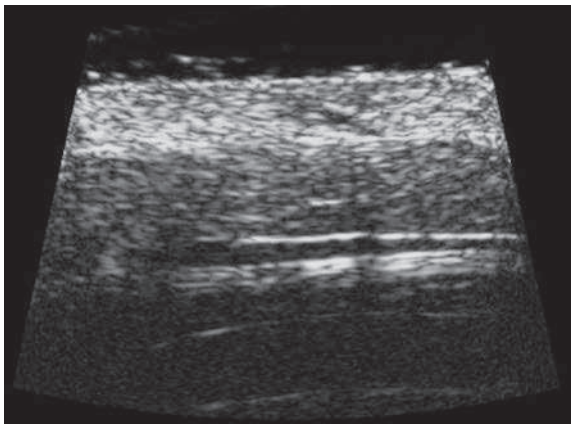
The parameter $M$ estimated from the $K$-distribution model depends on the actual number of scattering sites per resolution cell, as well as the uniformity of the backscattering coefficient. The type and distributions of scatterers are intrinsically related to the type of tissues that the ultrasound beam is passing through. Therefore, the $M$ parameter can be used to distinguish between regions differing in a special density of the scatterer or between regions of a varying scatterer's cross-section, and, as a consequence, can be used as a parameter for tissue characterization.

In this study, by comparing the statistics of empirical data to the Rayleigh and $K$-distributions, the validity of the distribution as an accurate descriptor of the statistics of the signal envelope was evaluated.

## 3. Measurment procedure

Skin tissues were examined *in vivo*. The measurements were performed in the dermis in various parts of the body. Two kinds of data were recorded. The measurements were carried out in the regions of skin where the basal cell carcinoma was diagnosed and also, for all the patients, the data from healthy fragments of the skin were recorded. Figure 2 shows B-scans images of the healthy skin and basal cell carcinoma.

a)



b)

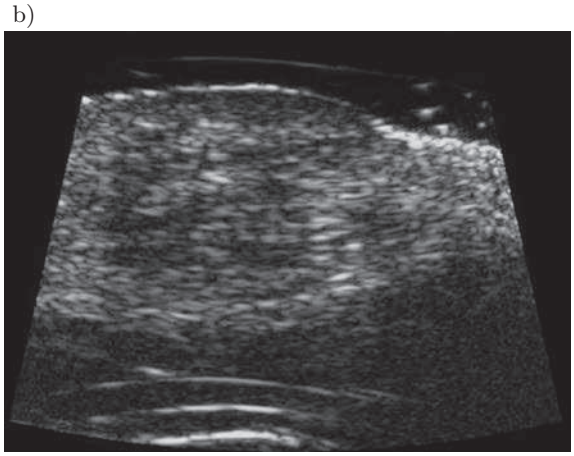


Fig. 2. B-mode images of a healthy human dermis (a) and a basal cell carcinoma (b).

The skin echoes were acquired with an ultrasonic scanner operating at the frequency of 30 MHz (Lewandowski, Nowicki, 2006). The scanner performed a sector scan with the 10 Hz image frame rate. The scattered echoes were sampled at the frequency of 200 MHz with a 12 bits resolution. In this study we have used a 20 μm thick spherical transducer (with a 3 mm diameter and 8.6 mm focal length) made of a modified PZT 37 deposited on the PZT substratum using the thick-film technology (Ferroperm, Denmark).

## 4. Signal processing

Prior to statistical evaluations the received RF signals were compensated for the system TGC (Time Gain Compensation) and for the attenuation.

The attenuation coefficient $\alpha(f)$ of the skin was determined for each case separately, using the spectral difference technique based on a comparison of the power spectra of the signals backscattered at different depths in the tissue (Piotrzkowska *et al.*, 2009).

For the compensation of attenuation the following algorithm was used (Litniewski *et al.,* 2011). First, the spectrum of the attenuated signal (FA) was calculated. Next, a synthesis of a new signal $F(\cdot)$ on the basis of spectral components of the backscattered signal was performed. During the synthesis, the amplitudes of spectral components were increasing with the increasing value of the depth coordinate corresponding to the penetration depth and the value of attenuation coefficient $\alpha_0$. This process is described by the formula:

$$F(t_i) = \sum_{k=1}^{G} FA_k \exp(\alpha_0 \cdot f_k \cdot v \cdot t_i) \cdot \exp(-j \cdot 2 \cdot \pi \cdot f_k \cdot t_i), \quad (9)$$

where $k$ stands for the index of the spectral component, $f_k$ denotes the frequency, $FA_k$ is a complex spectrum of the backscattered signal, $v$ denotes the phase velocity of the longitudinal acoustic wave in the skin, $\alpha_0$ is the attenuation coefficient, and $t_i = i \cdot \delta t$ stands for time, where $\delta t$ is a time step given by the signal sampling rate. The summation is carried over the whole range of frequencies of the backscattered signal ($G$). The real part of $F(\cdot)$ is the desired backscattered signal compensated for attenuation.

After the application of the compensation procedures the Hilbert transform was used to obtain the signal envelope. Figure 3 shows the received signal after the TGC and attenuation compensation and its envelope.

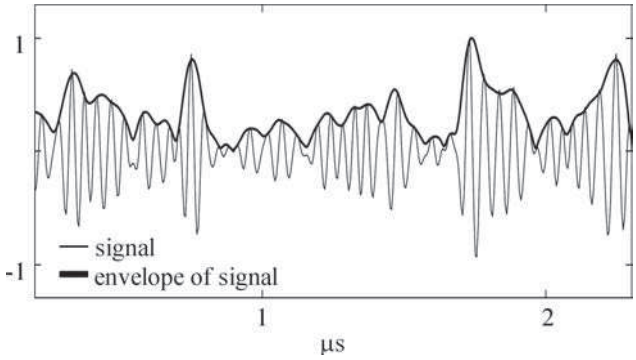



Fig. 3. RF signal after the TGC and attenuation compensations and its envelope.

## 5. The influence of focusing

Computation of the quantitative parameters requires a compensation for the system dependent effects because the recorded signals depend on both the tissue properties and the device used in recording of the signals. When a focused transducer is used, the variation in the beam size along the path of the beam leads to changes in the number of scatterers contributing to the resulting echo-signal from the tissue (at the focus, the beam size is small and hence a smaller number of scatterers contribute to the resulting signal as compared to the place away from the focus where the beam is broader). Therefore, the zone near the focus where the influence of focusing on the results (the effective number of scatterers) is negligible was determined empirically.

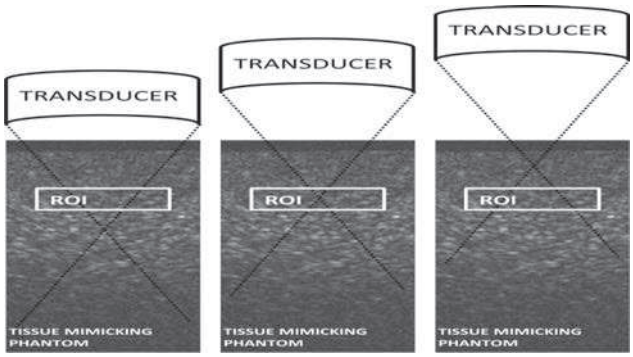



Fig. 4. Diagram of the measuring system which was used in the experiment to determine the influence of focusing on the value of the M parameter. The data were collected from the same ROI (region of interest) placed at a varying distance from the focus.

For each of the 20 transducer positions the same ROI (region of interest) of a tissue mimicking phantom was analyzed. For one of them the ROI was positioned at the transducer's focal zone and for the other the ROIs were positioned above and below the focus. The transducer was axially moved and the data were collected with the step of 0.25 mm. The effective number of scatterers was computed for all the 20 locations using the method described in the previous section.

The results revealed an important influence of the focus position on the value of the $M$ parameter (Fig. 5) computed in the ROI. We have found that the $M$ parameter is almost constant ($\pm 20\%$) in the 2 mm length zone centred at the focus. So, during an analysis of data from the skin, the effective number of scatterers was calculated for the ROIs which were localized at the distance from the focus of the transducer not exceeding 1 mm.

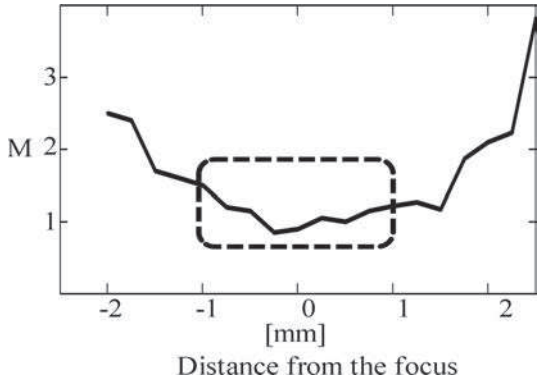



Fig. 5. The curve illustrates the variation in the value of the effective number of scatterers as a function of the distance from the focus.

## 6. Results

To determine the applicability of the $K$-distribution in modelling of statistics of the ultrasonic backscatter from the human dermis, a comparison between a histogram of experimental data obtained from the healthy human skin and the $K$- and Rayleigh distributions was done. Ten echo-data sets obtained *in vivo* from the healthy skin were used. Figure 6 shows an example of the signal envelope values histogram and the Rayleigh and $K$-distributions.

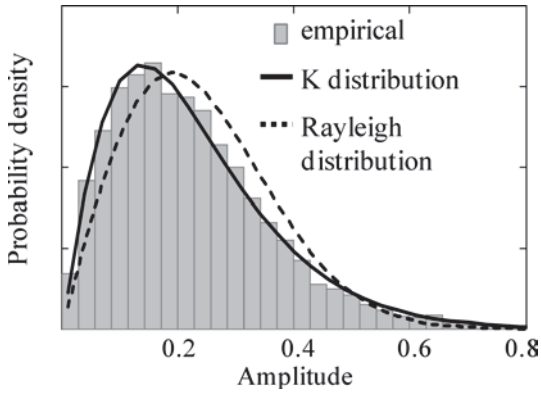



Fig. 6. Theoretical Rayleigh and $K$-distributions and a histogram of empirical data obtained *in vivo* at the nape of a neck.

To indicate which of the distributions, Rayleigh or $K$, is more appropriate to model the statistics of the envelope of the echo-signal, the mean square error (MSE) was calculated. The values of the mean square error obtained for empirical data compared to the Rayleigh and $K$-distributions ranged from 0.073 to 0.09 and from 0.008 to 0.021 respectively. The mean of the MSE calculated for the approximation of the data with the $K$-distribution was equal to 0.012 and was about eight times lower than the mean of the MSE calculated for the Rayleigh distribution approximation (mean of the MSE = 0.083). The obtained results pointed evidently to a closer fit of the data to the $K$-distribution.

In the next step of the analysis, the $K$-distribution and the parameter $M$ (effective number of scatterers) were used for a characterization of the skin lesions. Fourteen cases of basal cell carcinoma were analyzed.

Figure 7 shows examples of histograms determined for the healthy skin and for the basal cell carcinoma.

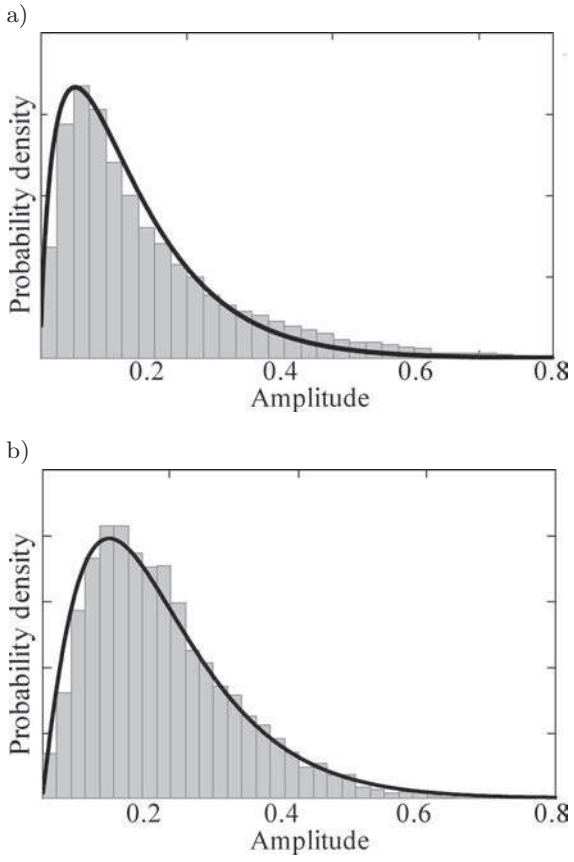



Fig. 7. Histograms determined (a) for a skin with the diagnosed basal cell carcinoma and (b) for the healthy skin.

For all considered cases the values of the effective number of scatterers obtained for the skin cancer were lower than the values of the $M$ parameters calculated for the healthy skin. The results are presented in Table 1.

Table 1. $M$ parameters calculated for the basal cell carcinoma (BCC) and healthy skin (HS).

| BCC | HS |
|---|---|
| 1.12 | Data Not Available |
| 1.16 | 1.61 |
| 0.91 | 1.61 |
| 1.20 | 1.93 |
| 0.82 | 1.98 |
| 1.12 | 2.07 |
| 0.91 | 1.86 |
| 1.04 | 1.93 |
| 1.17 | 2.07 |
| 1.21 | 1.68 |
| 0.87 | 1.76 |
| 0.91 | 2.13 |
| 0.84 | 1.93 |
| 1.09 | 1.87 |

The mean value of the effective number of scatterers for the healthy skin was equal to 1.88 (st. dev. = 0.16) and ranged from 1.61 to 2.13, whereas the mean value of the parameter M for skin lesions was equal to 1.03 (st. dev. = 0.14) and ranged from 0.82 to 1. 21.

## 7. Conclusions

Our study proved that the quantitative ultrasound can provide additional information that is potentially useful for the skin lesions diagnosis. The presented results showed that the $K$-distribution, which encompasses a wide range of distribution functions, seems to be a good model to describe the envelope statistics of signals from the human dermis. Moreover, the parameter $M$ of the $K$-distribution is sensitive to the changes of the skin tissue microstructure.

Variation of the parameter $M$ probably results from remodelling of the tissue structure in the case of pathological lesions. The basal cell carcinoma is characterized by clusters of tumor cells which are much bigger than healthy skin cells. The $K$-distribution is sensitive to the number and uniformity of scatterers comprised within the resolution cell. The drop of the $M$ parameter of the $K$-distribution for the BCC can be explained by a lower spatial density of scaterrers (cell clusters) as compared to the spatial density of cells in the healthy skin. However, a low number of the studied cases does not allow us to draw far-reaching conclusions regarding the usefulness of the $M$ parameter of the $K$-distribution for the skin lesions diagnosis. Nevertheless, the results encourage us to extend the research, since a lot of future studies must be performed to assess the diagnostic usefulness of the proposed method.

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