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STATISTICAL PROPERTIES OF WAVELET TRANSFORM COEFFICIENTS OF BACKSCATTERING SIGNAL FROM SOFT TISSUES AND THEIR PHANTOMS

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The paper contains the wavelet approach to registered backscattered RF signals from two different cases. First, the wavelet analysis has been performed for RF signals registered from soft tissue phantoms .The second case is the wavelet analyses of RF scattered signals from regions of healthy and BCC changed human skin. The three phantoms made from tissue-mimicking material with different structures have been measured. We claim that there are visible differences in the statistical parameters of wavelets coefficients of signals between healthy and BCC changed skin regions as well as between phantoms without scatterers and with different number of strong small scatterers.

INTRODUCTION

The aim of the study is to investigate the differentiation of three structurally various soft tissue phantoms and, to localize regions with micro-structural changes due to regions of healthy and ill skin using wavelet method. The method of wavelet transform has been applied to analyze the backscattered RF signals obtained from ultrasounds transducer used to irradiate different materials. The reason of applying the wavelet approach to this signal analysis, besides classical methods based on Fourier decomposition, is a strong need to improve parametric differentiation of soft tissue regions or their phantoms, which until now have not used the wavelet methods. During the performed experiment, cf. [1], three types of phantoms were used: one of them was pure phantom (it will be named further as Phantom 1), the second one has glass balls inside with density 6 items per mm3 (Phantom 2), the third one has density 30 balls per mm3 (Phantom 3). To develop the theoretical and experimental basis for temperature measurement during heating of internal regions of soft tissues we would like at first to find an answer to the question what parameters characterizing the ultrasonic acoustic signal, being recorded during the heating, are significantly associated with the local temperature increase. First step is to study acoustic properties of self fabricated soft tissue phantoms by different approaches to proof efficiency of methods used in the future analysis, which will be more complicated in the case of heating. The paper contains the wavelet approach of registered RF signal backscattered by soft tissue phantom samples.

A differentiation of the healthy human skin regions and the skin lesions regions (BCC basal cell carcinoma) basing on a statistics of the envelope of ultrasonic echoes has been performed in papers [6-7] . The echoes envelopes distributions were modeled using Rayleigh and K-distribution. The results concern in characterization the changes in tissue regions by different values of a characteristic parameter of the K-distribution, namely the effective number of scatterers. Inspirited with that results we have used the same digital dataset and we have performed wavelet analysis. The Daubechies 6 wavelet was chosen as analyzing wavelet. There have been chosen because of their form similar to the shape of reflected impulse signal, see Fig. 1. This decision is quite arbitrary, one shall consider different wavelet shapes to be sure that the use of Daubechies 6 is in some sense optimal.

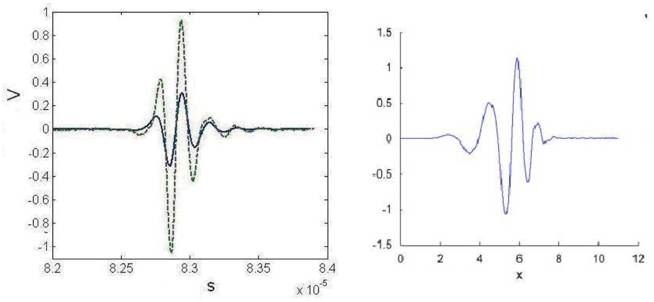

Fig.1. Left: Reflected impulse signal in water - dashed line and the same signal transmitted thru Phantom A and reflected – continuous line. Right: Daubechies 6 wavelet.

1. GENARAL CONCEPT OF WAVELET APPROACH

Wavelet techniques are widely used in signal processing now (see e.g. [2-3]).

The main idea is that any function $f(t)$ from the Lebesque space $L^2(R)$ (functions integrable with the 2nd power) may be represented in the form

$$f(t) = \sum_k s_{j_n,k}\varphi_{j_n,k} + \sum_{j \geq j_n} d_{j_n,k}\psi_{j_n,k} \ ,$$

where $\psi_{j_n,k}$ are basic wavelet functions depending of chosen analyzing wavelet, satisfying the conditions $\psi_{j,k} = 2^{\frac{j}{2}}\psi\left(2^j t - k\right)$, $\varphi_{j_n,k}$ are scaling functions, coefficients s and d are calculated.

We choose Daubechies 6 wavelets family as analyzing wavelet, cf. [2]. This wavelet family is wide-used because of their possibility of pre-defined properties. The wavelet and scaling function from the Daubechies family has no analytical formulae and they may be calculates using following relations

$$\varphi(t) = \sqrt{2}\sum_k h_k \varphi(2t-k),$$

$$\psi(t) = \sqrt{2}\sum_k g_k \varphi(2t-k),$$

where $\sum_k \left|h_k\right|^2 < \infty$.

To have the coefficients for Daubechies family, cf. [3], the orthogonality of scaling functions must be ensured, so

$$\sum_k h_k h_{k+2m} = \delta_{0,m}.$$

As well as the orthogonality of wavelets with respect scaling functions

$$\sum_k h_k g_{2k+m} = 0.$$

Its solution shows how the scaling function coefficients g_k may be represented from the wavelet function coefficients h_k

$$g_k = (-1)^k h_{2M-1-k}.$$

Two other additional conditions are the orthogonality of the wavelet function to the polynomials of degree up to $M-1$

$$\sum_k k^n g_k = 0 \text{ or } \sum_k (-1)^k h_k = 0,$$

and the normalization condition

$$\sum_k h_k = \sqrt{2}.$$

The Daubechies 6 has compact support, namely, the k-level wavelet function ψ_k has support $[0, 2k+1]$, and 6 vanishing moments. The coefficients of scaling function are calculated in [3] and their values are: $h_1 = 1.14111692$, $h_2 = 0.650365$, $h_3 = \text{-}0.1909344$, $h_4 = \text{-}0.12083221$, $h_5 = 0.0498175$. Coefficients for wavelet functions may be obtained from (3).

2. WAVELET APPROACH TO PHANTOM SIGNAL PROCESSING

The main idea of this investigation was to extrapolate method of wavelets analysis of fetal heart-rate signals used in [2] to the data of the described experiments.

The Daubechies 6 wavelet was chosen as analyzing wavelet. There have been chosen because of their form similar to the shape of transmit impulse signal. The whole datasets were investigated for 12 approximation levels, so $j_n = 12$.

Using MathLab Wavelet Toolbox [5] it was obtained the decomposition of original signals for 12 levels. The example is shown on the Figure 4. Here s denotes the original signal, a_1 - a_{12} show the signal reconstruction according to corresponding approximation level, d_1 - d_{12} are detailisation coefficients of corresponding level and cfs shows the coefficient distribution graph.

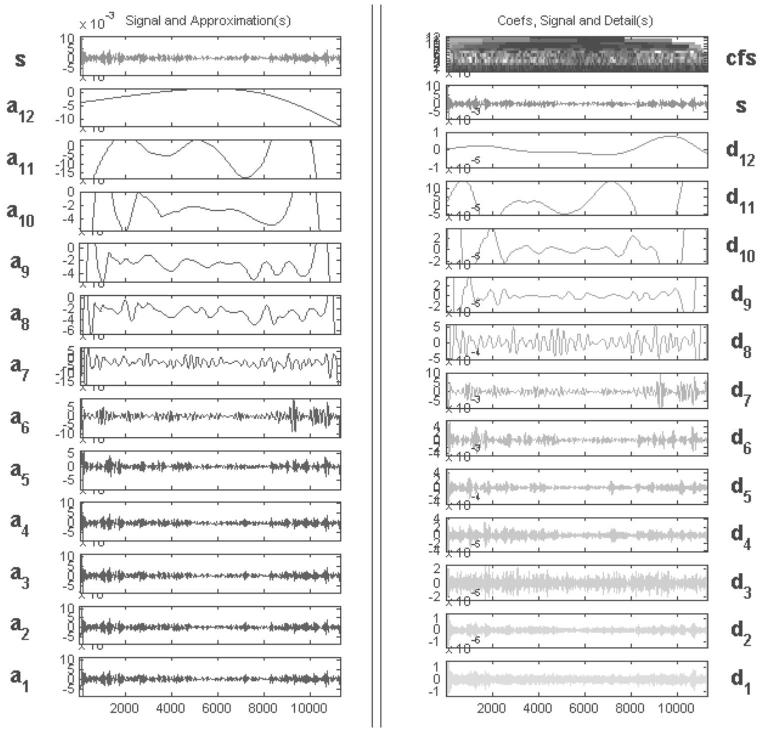

Fig. 2. Example of signal decomposition for 12 levels.

In the paper [8] the comparison of decompositions of pure signal on different levels have been discussed.

It was conclude that because matrix material is the same in the 3 phantoms the differences arising in analysis are due to number of scatterers. It has been observed that on the 9-level of approximation there appear similarities between Phantom 1 and Phantom 3, while Phantom 2 is qualitatively different. This fact is even stronger evident when 12-level of approximation is taken into account. In the matrix material we have rather uniformly distributed weak scatterers and the amplitude of reflected wave fluctuations are also not high.

The comparatively large number of glass balls can be considered to be also distributed uniformly and they dominate in the backscattered signal amplitude fluctuations (higher than in the case of pure matrix Phantom 1) giving rise to similarities in wavelet analysis. Contrary, comparatively low density (Phantom 2) of strong scatterers, and, at the same time existing noise from weak scatterers, introduce the double structure of random character of backscattered field. It is probably the difference visible in wavelet form of 12 level approximation. To discover other differences we have apply wavelet analysis to envelope of signals, but without any kind of compensations. The differences in coefficients on different levels are depicted on Fig. 3 below.

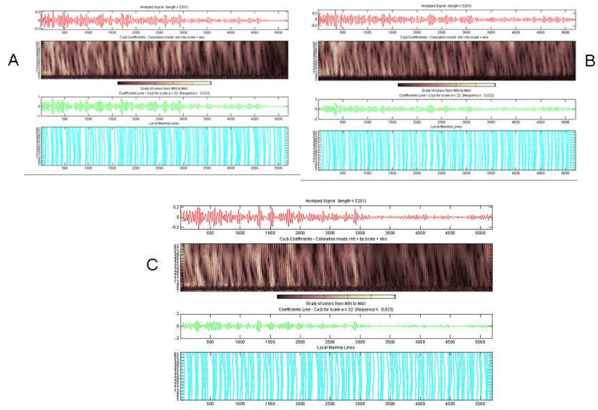

Fig. 3. Signal envelope decomposition from 3 phantoms

The large number of scatterers (Phantom C) are „visible" on the two-dimensional picture of wavelet coefficient distributions - stronger fluctuations in the right side of pictures (left side is less visible because we did not compensate the attenuation). The tendency to differentiate between "columns" in the pictures i.e. the same values of coefficients on successive scales, one can also notice in the case of moderately number of scatterers (Phantom B).

Besides MATLAB the software R has been used with toolbox WAVELET and MRA (Multi-resolution Analysis) to perform statistical analysis of wavelet coefficients on different level of signal approximations. The Beta distribution and Gamma unormalized and normalized distributions have been used to fit the histograms. The results are that better fitting is for both considered Gamma distributions. The values of Gamma parameters - shape and scale parameters - quite well differentiate our structures (i.e. glass ball densities) until 6-7 level of approximations, cf. Fig. 4 and Fig. 5.

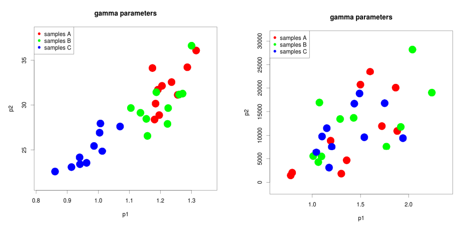

Fig. 4. Gamma unnormalized distribution coefficients : left - the 6th level of approximation right - 12 level of approximation

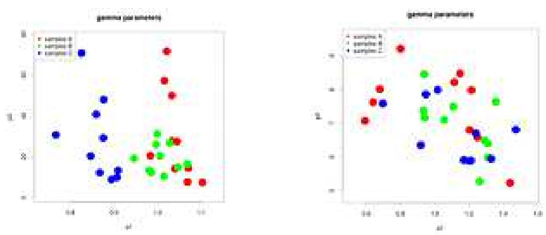

Fig. 5. Gamma normalized distribution coefficients : left - the 6th level of approximation right - 12 level of approximation

3. WAVELET APPROACH TO SKIN SAMPLES SIGNAL PROCESSING

As it was noticed the skin regions changed by BCC illness have been recognized by different values of K distribution shape parameter in [6]. We decided at first to repeat the idea but to use for statistics wavelet coefficients from level 6^{th} of approximations instead envelope statistics. The results are not satisfactory yet. We can see differences in shape K- distribution coefficient in healthy and ill regions, cf. Fig. 6, but this differences are also visible for simple statistics of wavelet parameters, cf. Fig. 7, 8.

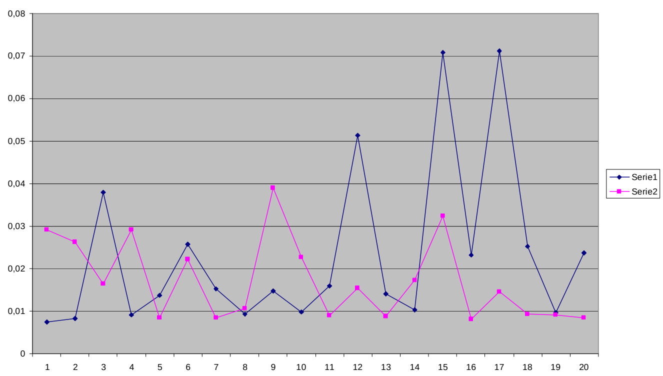

Fig. 6. Shape parameter of K-distribution of wavelet coefficients on 6^{th} level of approximation for healthy (Serie 1) and ill (Serie 2) skin.

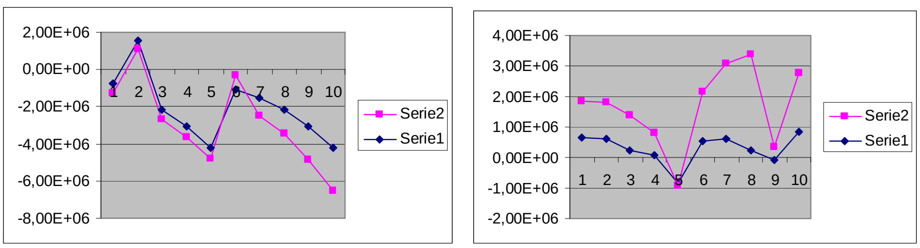

Fig. 7. Mean and Median of wavelet coefficients on 6^{th} level of approximation for healthy (Serie 1) and ill (Serie 2) skin.

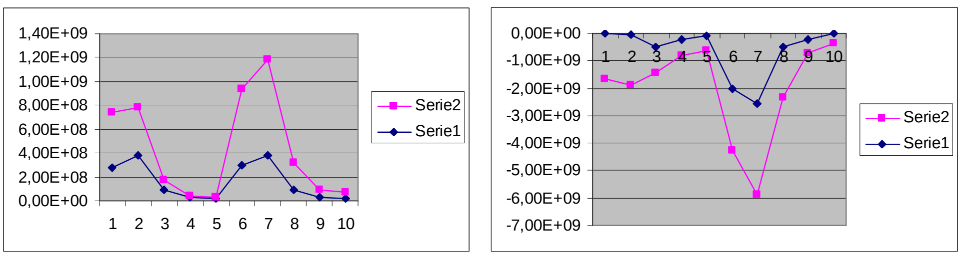

Fig. 8. Standard Deviation and Minimum Values of wavelet coefficients on 6^{th} level of approximation for healthy (Serie 1) and ill (Serie 2) skin.

The 2 dimensional wavelet diagram of the whole region scanned *in vivo* enables to recognize the ill regions visually, in a different way than it is done in B-scan mode picture, cf. Fig. 9.

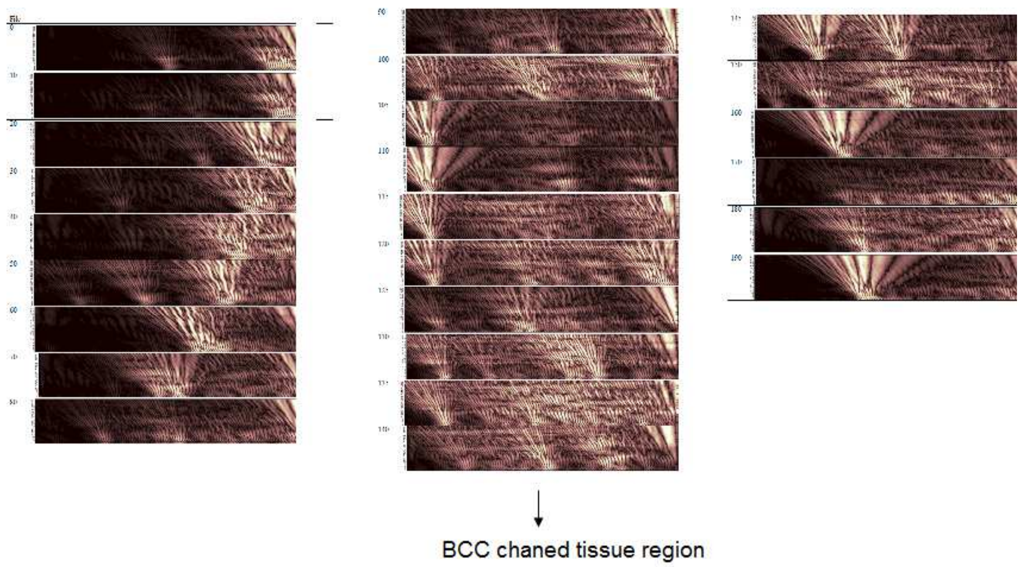

Fig. 9. 2D pictures of wavelet coefficients on different lines of A scans

4. FINAL REMARKS

The experimental data obtained from the registration of the backscattered signals of the initial ultrasound impulse formed our dataset used in the calculations. We divided our consideration into two problems: finding such signals properties which are due to different structure of three soft tissue phantoms and finding new ultrasonic markers of skin lesions (BCC). The data from *in vivo* performed measurements in human skin with the use of Microsonograph constructed in the year 2000 in the Ultrasounds Department of the Institute of Fundamental Technological Research we obtained by courtesy of H. Piotrzkowska. We can not claim that both our problems are solved. For the comparatively simple microstructure in Phantoms our results are more clear. The Gamma distribution parameters can be used to differentiate the 3 cases. The methods used here are new in this kind of real signals and our results can be treated as only introductory. We are able to calculate the statistically noticeable differences in regions of healthy and ill skin, but the more detailed analysis is still lacking.

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