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Wavelet approach to RF signal analysis for structural characterization of soft tissue phantom

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Abstract

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 transmitted by soft tissue phantom samples in the constant room temperature. Three phantoms with different structures have been measured. We claim that there is qualitative differences in the wavelets forms between phantom without scatterers and with seldom number of strong scatterers, while the large number of scatterers demonstrates qualitatively similar wavelet characteristics as phantom without scatterers.

1. Experiment

The aim of this study is to investigate the transmission properties of three different phantoms. During the performed experiment, cf. [1] in the same abstract book, 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 mm^3 (Phantom 2), the third one has density 30 balls per mm^3 (Phantom 3). In the Figures 1-3 the obtained RF signals are shown i.e. the amplitude of signals from oscilloscope.

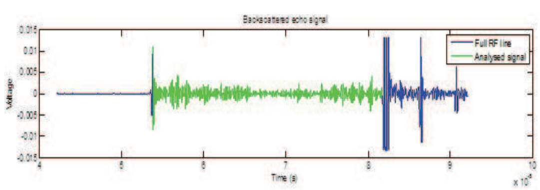

Figure 1. Phantom 1 – pure.

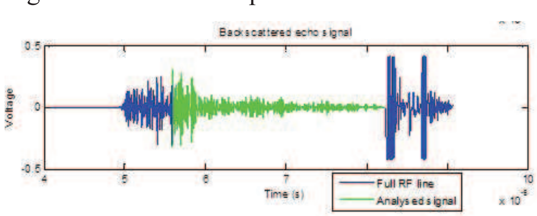

Figure 2. Phantom 2 containing 6 glass balls per mm^3.

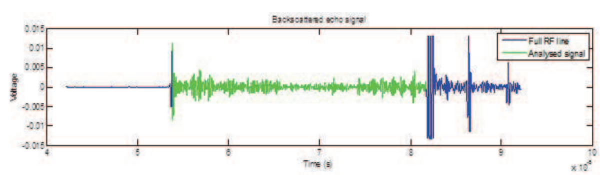

Figure 3. Phantom 3 containing 30 glass balls per mm^3.

The problem was how to distinguish these phantoms according to the different density of balls. Other methods of the comparison analysis are presented in [1] .

2. General concepts 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

$$f(t) = \sum_k s_{j_n,k}\varphi_{j_n,k} + \sum_{j \geq j_n} d_{j_n,k}\psi_{j_n,k} \, , \quad (1)$$

where $\psi_{j_n,k}$ are basic wavelet functions depending of chosen analyzing wavelet, satisfying the conditions $\psi_{j,k} = 2^{\frac{j}{2}} \psi(2^j t - k)$, $\varphi_{j_n,k}$ 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

$$\varphi(t) = \sqrt{2}\sum_k h_k \varphi(2t-k), \quad \psi(t) = \sqrt{2}\sum_k g_k \varphi(2t-k) \tag{1}$$

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

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

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

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

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

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

$$\sum_k k^n g_k = 0 \text{ or } \sum_k (-1)^k h_k = 0, \tag{3}$$

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: $h_1 = 1.14111692$, $h_2 = 0.650365$, $h_3 = -0.19093442$, $h_4 = -0.12083221$, $h_5 = 0.0498175$. Coefficients for wavelet functions may be obtained from (3).

3. 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.

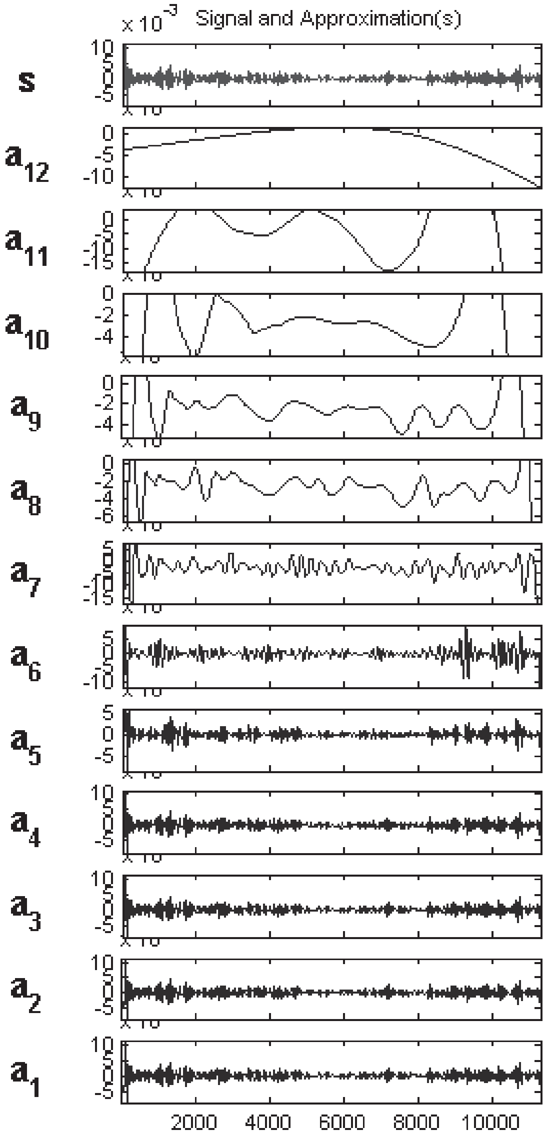

Figure 4. Exampe of signal decomposition for 12 levels.

4. Conclusions

Comparing the decompositions of three phantoms it can be seen that the 9-level approximation shows the trend to show the similarities between Phantom 1 and Phantom 3 (Figures 5, 7), while Phantom 2 is qualitatively different. This fact is even stronger evident when 12-level approximation is taken into account. The similar conclusion appears in statistical characteristics analysis of signal envelope, which is performed in [1]. There is a need to further study of wavelet analysis in finding temporal structural characteristic of soft tissue phantom especially when weaker scatterers will be considered. The lack of smooth transition from lack of glass balls (Phantom 1) to dense volume fracture of balls (Phantom 3) is supposed to be connected with the type of random distribution of weak and strong scatterers. The matrix material is the same in the 3 phantoms. 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 in wavelet form of 12 level approximation.

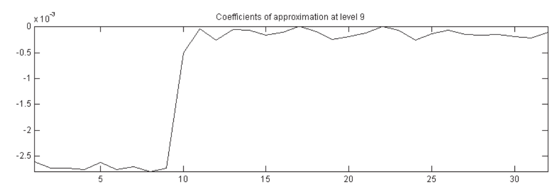

Figure 5. 9-level approximation for Phantom 1.

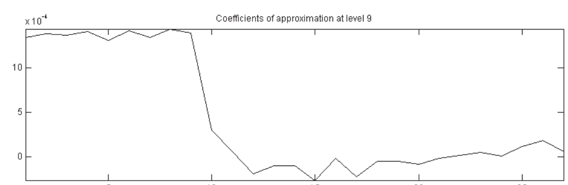

Figure 6. 9-level approximation for Phantom 2.

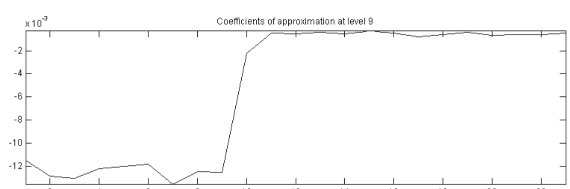

Figure 7. 9-level approxmation for Phantom 3.

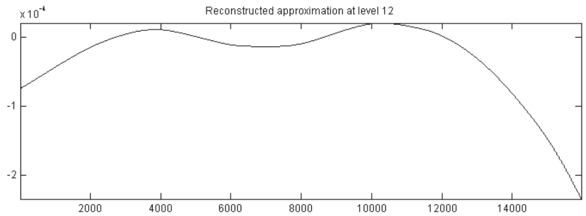

Figure 8. 12-level approximation for Phantom 1.

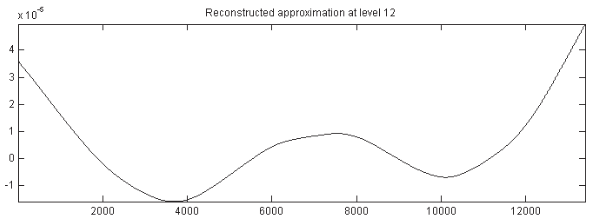

Figure 9. 12-level approximation for Phantom 2.

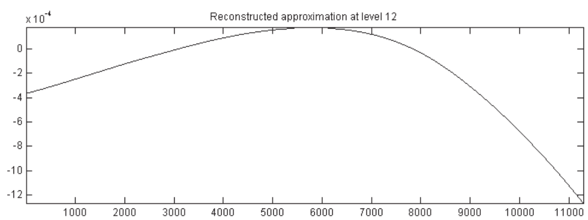

Figure 10. 12-level approximation for Phantom 3.

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