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w Krakowie

Review of the Doctoral Dissertation
of
Olga Dubrovina, M.Sc.

Title: **Wavelet Analysis of Ultrasonic Signals in Soft Tissue Characterization**
Supervisor: *dr hab. Barbara Gambin, prof. IPPT*

Ordered by dr hab. inż. Zbigniew Ranachowski, prof. IPPT
Secretary of the IPPT's Research Council

Introduction

The Dissertation of *Olga Dubrovina* consists of 123 pages and contains 7 chapters and 3 appendices. Her research is based on a number of her and her supervisor's references published in scientific journals and presented at conferences related to the topic, listed in Appendix C, which contains lists of the papers, book chapters and conference reports coauthored by Olga Dubrovina. The main dissertation's reference list includes 86 items related to the dissertation's subject.
The dissertation has a monographic form that conforms to the standards and requirements typical for scientific reports.

Dissertation's review

Research motivation, objectives and scope of the dissertation are briefly outlined in the Introduction where author formulates the main thesis of the dissertation as follows:

'To prove that by using wavelet distributions of the ultrasonic backscattered RF signals new markers (quantitative parameters) characterizing the soft tissue scattering microstructure can be found'.

It is worth noting that the author does not focus her considerations to a specific type of tissue or lesion but aims to verify the general signal processing tool – wavelet transform (WT) – for characterizing soft tissues.

To facilitate reading the contents the author presents a comprehensive flowchart that illustrates two main ways of analyzing ultrasonic signals concerned in the dissertation: the WT analysis of raw RF signals and the WT analysis of their amplitudes (envelopes). The first approach is used for the evaluation of mean scatter spacing while the second for tissue temperature tracking.

Chapter 1 provides general theoretical background, that is, the theory of linear and nonlinear wave propagation and wave absorption as well as the detailed presentation of the tools used in the dissertation for processing the backscattered ultrasound signals, i.e., the wavelet transform and the selected statistical distributions.

The discrete WT is applied in the dissertation both for signal filtering (de-noising) and for extracting features (scale index) used for modeling of scattering process that yield the numerical parameters used for quantitative characterization of the scatterers number. The theory, which relates the wavelet decomposition level to the signal periodical structure, is applied and the *signal index indsc* depending on the wavelet approximation level is defined and presented in some detail. The *mean scatterer spacing (MSS)* parameter, which quantifies the average periodicity in a RF signal caused by the periodical structure of scattering media is introduced. Both concepts have been adopted from the literature related to processing ultrasound signals.

Examples of statistical distributions, commonly used for building simple models of scattering in inhomogeneous media are introduced. The way of extracting numerical parameters from the statistics of the RF envelopes that are related to the scatterers number and their spatial distribution is outlined.

In Chapter 2 the author presents, previously published, own results of processing the raw RF backscattered signals from agar-gel samples gathered in the experiment performed by other researchers. The study illustrates how the quantitative parameters related to the effective scatterer numbers can be extracted by analyzing envelopes of the raw RF backscattered signals for samples with different number of scatterers. The conclusions presented in this chapter concerning the shape parameters of statistical distributions are of rather detailed character, specific for the analyzed data.

In Chapter 3 an analysis of the temperature changes in tissue during the heating process based on the registered changes in the ultrasound echo signals is presented. The investigation was performed using two sets of ultrasound data produced by other researchers who performed experiments on a special phantom of soft tissue. The phantom was fabricated to examine the temperature changes of the backscattered acoustic signal under the heating process. The processing results, presented in this chapter, concerning the K-statistics shape parameters of the WT processed data enabled distinguishing the regions with different temperature levels. The presented results, however, are of rather detailed character, specific for the analyzed data.

In Chapter 4 the author presents study of the WT processing of backscattered signals generated numerically from different types of scattering media. The random scattering signals used in this study were generated by means of the computer program available at the IPPT. Signal decomposition using the Daubechies wavelet on 4th level enabled separation of the media with different distributions random scatterers. Regular distributions of the scatterers could be detected by means of the scale index.

Results of a thread-phantom study, formerly published in the papers coauthored by the author, are presented in Chapter 5. It is shown how the RF signals backscattered from the self-made thread-phantom with predefined periodic structure can be used for the validation of the estimation accuracy of the MSS parameter. It is also shown that wavelet processing of the RF signals (scalogram) is capable of reducing the MSS estimation error.

The final Chapter 6 reports results of processing data obtained from an ultrasound examination of liver structure in vivo performed using a 3.3 MHz phase array by a radiologist. A-scans from the the acquired liver B-scan images in the preselected regions of interest were processed to evaluate the scale indices and to estimate the MSS. The estimated values of scale index indicated more periodic structure in the healthy areas than in the tumor areas.

The main conclusions of the dissertation, listed in Chapter 7, indicate that processing of the RF signals using both continuous and discrete wavelet transform generally improves precision of the MSS estimates. The scale index, proposed by the author, estimated from the ultrasonic RF signals by means of the discrete WT can be used as a reliable measure of the structure chaoticity, and thus, can be used for tissue characterization.

Summary and conclusion

The dissertation addresses a contemporary and modern problem of tissue characterization based on the parameters, which can be obtained using advanced signal processing techniques applied for ultrasound signals that are available today from modern ultrasonographs. Performance of the signal processing techniques proposed by the author, which include wavelet transform and statistical analysis of the RF signals, have been investigated on the real and simulated ultrasound data.
The following positive features of the dissertation are worth naming:

- The dissertation research generates significant novel knowledge in the area of processing ultrasound signals using wavelet transform.
- The dissertation demonstrates solid author's understanding of the state-of-the-art in the area of applied signal processing as well as her knowledge of the most important literature.
- The methodology is scientifically sound and based on the theoretical background extensively described in the first chapter.
- The dissertation is interdisciplinary since it is concerned with processing of ultrasound signals acquired in biological systems.

The following critical comments points have to be mentioned as a potential weakness of the thesis:

- The results are not discussed in relation to the research of others, i.e., very few reports of other researchers that may be directly related to the candidate's results are mentioned.
- Novelty of the candidate's results is poorly emphasized, i.e., the presented results are not compared to the former results obtained by other authors using more classical methods.
- Almost all chapters (except Chapter 7) report the results obtained for the experimental/simulated data gathered by other authors.
- Details concerning the WT application to B-scan data are not explained in a crystal clear way, which evokes the question: why the WT was used to the aggregated A-scans only and the 2D WT was not considered?
- Figure captions are in many cases insufficiently informative and the detailed explanation can be found in the text only.
- Fonts used at the axes in many 2D plots are too small to be legible.
- English is poor in some parts, especially in the introduction. Some terms used are misleading, e.g. 'density differentiation' associates at first with the mathematical operation of calculating derivative.

It should be concluded, however, that despite the above critical comments the candidate's contribution to the research in her dissertation and her publications is sufficiently large to award her with a PhD, which means that **I am recommending the IPPT's Research Council to initiate the procedure of public defense of Olga Dubrovina's doctoral thesis.**

Uppsala 15 August, 2019.