Advanced Spectral Analysis Methods for Quantification of Coherent Ultrasound Scattering: Applications in the Breast

Ivan M. Rosado-Mendez

Under the supervision of James A. Zagzebski and Timothy J. Hall

At the University of Wisconsin-Madison

6/2/2014

The goal of this dissertation was to improve the diagnostic value of parametric images generated from Quantitative Ultrasound (QUS) methods based on the power spectral density (PSD) of radiofrequency echo signals. This was achieved by testing for local adherence to conventional QUS assumptions that echo signals originate from incoherent scattering, and that signals are stationary over PSD estimation windows. For this purpose, we designed a novel algorithm that empirically evaluates the statistical significance of coherent-scattering signatures in the echo signals. Signatures are quantified through a set of optimized metrics describing the stationary or non-stationary features of the echo signals. We compared Nakagami-model based metrics and model-free metrics of the statistics of the echo signal amplitude for analyzing stationary features. For non-stationary features, we advanced the use of the echo-signal generalized spectrum by comparing single- and multi-taper estimators of this spectrum to the time-domain singular spectrum analysis method. Tests of statistical significance were done through empirical comparisons with values of the same metrics estimated from a uniform reference material exhibiting incoherent scattering. The metrics that quantify these features were selected after simulation- and phantom-based optimizations centered on the task of creating parametric images, where tradeoffs must be made between spatial resolution, accuracy, and precision. The connection of the analyses of the stationary and the non-stationary features provided a way to estimate descriptors of the tissue organization scales below and above the resolution limit imposed by the size of the acoustic pulse. A preliminary application of the developed algorithm was done on echo data from human breast lesions scanned *in vivo*. Results supported the idea of a more homogenously random distribution of subresolution scatterers within invasive ductal carcinomas than within fibroadenomas. Results also indicated the importance of the anisotropy of the scattering process to distinguish between different lesion types. Future work will refine the tools developed here and explore the connections between these backscattered echo characteristics and tissue microstructure studied through microscopy.