GPU Accelerated 3D Nonlinear Time Domain Inversion of Realistic Breast Phantoms with Multiparameter Optimization

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The detection of early-stage breast tumors with microwave imagers has received considerable attention in the recent years. However, reconstructing the complex dielectric profile of the realistic breast phantom remains a computationally costly challenge. This paper presents a GPU accelerated 3D time-domain nonlinear inverse scattering technique to effectively reconstruct the complex dielectric profile of realistic breast phantoms.

The 3D nonlinear time domain inversion technique is based on the Born iterative method (BIM). BIM assumes that in the first iteration, the total field inside the object can be approximated by the incident field. Within each iteration of the BIM, both forward problem and inverse problem are solved once. Here the calculation of both the forward problem and the inverse problem are accelerated by the Tesla C2075 GPU from Nvidia. The acceleration method is based on the Compute Unified Device Architecture (CUDA) introduced by Nvidia to leverage the parallel computation power of its general-purpose GPU. In our method, the forward problem is solved with the Auxiliary Differential Equation Finite Difference Time Domain method (ADE FDTD) with the convolution perfectly matched layer (CPML). The main ADE FDTD algorithm to update the E and H fields, and the algorithm to update six CPML boundaries at the six sides of the domain are accelerated by different GPU kernels. Within each kernel, all the field points are calculated in parallel. However, each kernel is launched sequentially to avoid data race because different kernels may update the same field in the same region considering the overlap of PML slabs. The inversion is carried out with a regularized local optimization process, wherein a multi-parameter optimization scheme is designed to accommodate the three sets of unknowns, namely the real part of permittivity, conductivity, and a dispersion parameter. This process is also accelerated with the GPU while formulating the inversion matrix and solving the matrix with the conjugate gradient method. The acceleration has achieved a speedup factor of at least 25 for solving the forward problem and a speedup factor of 5 for the inversion while reconstructing the realistic breast phantom at 2mm voxel size. The realistic Wisconsin breast phantoms derived from MRI data are used here. The phantom provides a single-pole Debye relaxation model based complex dielectric profile of the breast tissue over our frequency of interest 0.5 to 3.7GHz. Imaging results for several phantoms will be shown and will demonstrate the reconstructed spatial distribution of the fiber glandular tissue of the breast. The comparison of the total computation expense between utilizing GPU and CPU will also be presented.