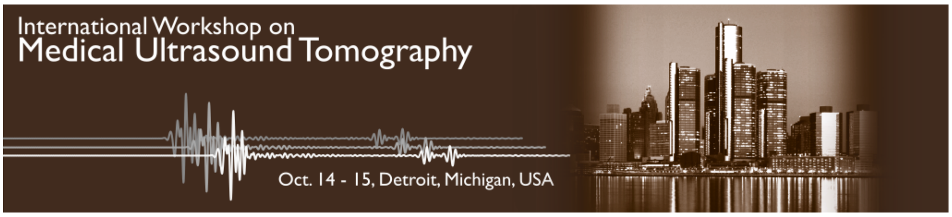

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3D Wave-Equation-Based Finite-Frequency Tomography for Ultrasound Computed Tomography

Ultrasound Computed Tomography (USCT) has great potential for 3D quantitative imaging of acoustic breast tissue properties. Typical devices include high-frequency transducers, which makes tomography techniques based on numerical wave propagation simulations computationally challenging, especially in 3D. Therefore, despite the finite-frequency nature of ultrasonic waves, ray-theoretical approaches to transmission tomography are still widely used.

This work introduces finite-frequency traveltime tomography to medical ultrasound. In addition to being computationally tractable for 3D imaging at high frequencies, the method has two main advantages: (1) It correctly accounts for the frequency dependence and volumetric sensitivity of traveltime measurements, which are related to off-ray-path scattering and diffraction. (2) It naturally enables out-of-plane imaging and the construction of 3D images from 2D slice-by-slice acquisition systems.

Our method rests on the availability of calibration data in water, used to linearize the forward problem and to provide analytical expressions of cross-correlation traveltime sensitivity. As a consequence of the finite frequency content, sensitivity is distributed in multiple Fresnel volumes, thereby providing out-of-plane sensitivity. To improve computational efficiency, we develop a memory-efficient implementation by encoding the Jacobian operator with a 1D parameterization, which allows us to extend the method to large-scale domains. We validate our tomographic approach using lab measurements collected with a 2D setup of transducers and using a cylindrically symmetric phantom. We then demonstrate its applicability for 3D reconstructions by simulating a slice-by-slice acquisition systems using the same dataset. The result is shown in the Figure, where we also analyse the vertical resolution using estimations of point-spread functions calculated from Hessian-vector products. We conclude showing that the vertical resolution could be controlled by appropriate designs of the acquisition system.

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