

Adapted nonlinear full waveform inversion for ultrasound computed tomography of musculoskeletal tissue in children

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Background, Motivation and Objective

B-mode ultrasound (US) has long been the primary modality for diagnosing musculoskeletal tissue in children. Because of the large impedance contrast between hard and soft tissues, US can only see the outer surface of bones, not what lies within. In this context, linear ultrasound computed tomography (USCT) has been able to visualize musculoskeletal morphologies with appropriate signal processing, but has not been able to provide quantitative maps. To overcome these limitations, a nonlinear full waveform inversion (FWI) algorithm is implemented to provide quantitative maps, and evaluated on anatomical phantoms.

Statement of Contribution/Methods

The FWI is a parametric imaging method that is based on the full numerical modeling of wave propagation, and on the iterative minimization of a cost function to determine the physical parameters (in this work : geometry and impedance). The mean-square solution was calculated using the quasi-Newton technique, which uses information based on second-order derivatives in order to accelerate convergence, and the gradient of the cost function was calculated using the adjoining field method. The important difficulty related to the strong non-linearity of the cost function is that gradient-based minimization algorithms only converge to the solution if they are started close to the global minimum of possible values. In this work, we exploited the geometry provided by the linear USCT as a priori information for the FWI. Experiments were conducted, using a 1-MHz circular array on a newborn arm phantom containing blood vessels and joined bones (figure).

Results/Discussion

By comparing USCT and μ CT as a reference, organ morphometry was made possible. The blood vessels in the arm phantom were differentiated, and so were the different bones. The linear USCT shows artifacts due to various uncontrolled physical processes, although the dimensions of the soft tissue and bone contours are satisfactory to differentiate the regions of interest. This a priori information was used to reconstruct the acoustic impedance of the several tissues of the phantom. The resolution gain for the bones reaches 1784%, but the resolution of soft tissues contours (especially blood vessels) is degraded. This is due to biased soft tissue values that are trapped in local minima, even though a frequency hopping method was used, and strict stopping criteria defined.

