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Characterizing the elastic property distribution of soft materials nondestructively

Goenezen, Sevan, sgoenezen@tamu.edu; Mei, Yue, Texas A&M University, United States

ABSTRACT

Soft materials have the advantage that their subsurface structure may be imaged utilizing imaging modalities such as ultrasound, magnetic resonance imaging, computed tomography (CT) scans, and optical coherence tomography. In recent decades subsurface displacement fields were successfully measured using these imaging modalities. These displacement fields are of time-harmonic, transient, or quasi-static nature and can be used to solve an inverse problem in elasticity to determine the elastic material property distribution within the region of interest of the soft material. One important application area is in the detection and diagnosis of diseased tissues, such as breast tumors. This can be done as tumors are often stiffer than their background tissue, and based on the stiffness contrast they can be visualized and distinguished from their surrounding healthy tissues.

We will present the solution of the inverse problem in finite elasticity for quasi-static displacement fields. Here, the quasi-static displacement fields may be determined by taking a sequence of ultrasound images while slowly compressing the tissue with the ultrasound transducer. From this sequence of ultrasound images one may determine the displacement fields utilizing well-developed cross-correlation techniques. We solve the inverse problem iteratively by posing it as a constrained optimization problem, where the difference between a measured and computed displacement field is minimized in the L-2 norm and in the presence of Tikhonov regularization. The computed displacement field satisfies the constraint, which are the equations of equilibrium and solved using finite element methods for the current estimate of the elastic property distribution. We model the material to be hyperelastic with a strain energy density function of exponential form and two elastic property parameters: the shear modulus describes the linear elastic behavior, whereas the nonlinear elastic property describes the rate at which the material is stiffening at large strains [1]. In addition, we assume that the material is isotropic and incompressible. This method has been tested on hypothetical data and breast tumor patients [2] and proofed to be robust in the presence of noisy displacement data to recover the tumors. However, this method appears to be sensitive to the applied boundary conditions, i.e., the solution of the inverse problem for uniform boundary compression appears to be different than applying a linearly changing boundary compression. Obviously, the solution of the inverse problem lacks uniqueness with respect to changing boundary conditions. We realize that the uniqueness issue here is primarily because of the formulation of the displacement correlation term in the objective function. We provide a new formulation and show that this leads to a “more unique” solution of the inverse problem and improves the overall contrast.

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