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Model-based elastography: a survey of approaches to the inverse elasticity problem

Abstract

Elastography is emerging as an imaging modality that can distinguish normal versus diseased tissues via their biomechanical properties. This article reviews current approaches to elastography in three areas — quasi-static, harmonic, and transient — and describes inversion schemes for each elastographic imaging approach. Approaches include: first-order approximation methods; direct and iterative inversion schemes for linear elastic; isotropic materials; and advanced reconstruction methods for recovering parameters that characterize complex mechanical behavior. The paper's objective is to document efforts to develop elastography within the framework of solving an inverse problem, so that elastography may provide reliable estimates of shear modulus and other mechanical parameters. We discuss issues that must be addressed if model-based elastography is to become the prevailing approach to quasi-static, harmonic, and transient elastography: (1) developing practical techniques to transform the ill-posed problem with a well-posed one; (2) devising better forward models to capture the transient behavior of soft tissue; and (3) developing better test procedures to evaluate the performance of modulus elastograms.

1. Introduction

Elastography is an emerging imaging modality that exploits differences in the biomechanical properties of normal and diseased tissues (Krouskop *et al.*, 1998; Samani *et al.*, 2007; Sarvazyan *et al.*, 1995; Parker *et al.*, 2011). Several groups have investigated the diagnostic value of elastography in various clinical settings; these include detecting and characterizing atherosclerotic plaques (de Korte *et al.*, 2002; de Korte *et al.*, 2000; Doyley *et al.*, 2001; Brusseau *et al.*, 2001; Woodrum *et al.*, 2006); guiding minimally invasive therapeutic techniques (Kallel *et al.*, 1999; Righetti *et al.*, 1999; Varghese *et al.*, 2003); and improving the differential diagnosis of breast and prostate cancers (Hiltawsky *et al.*, 2001).

Elastography was developed in the late 1980s to early 1990s to improve the diagnostic value of ultrasonic imaging (Lerner and Parker, 1987; Lerner *et al.*, 1988; O'Donnell *et al.*, 1994; Ophir *et al.*, 1991), but the success of ultrasonic elastography has inspired other investigators to develop analogues based on other imaging modalities; these include magnetic resonance elastography (Muthupillai *et al.*, 1995; Bishop *et al.*, 2000; Weaver *et al.*, 2001; Sinkus *et al.*, 2000), and optical coherence tomography elastography (Khalil *et al.*, 2005; Kirkpatrick *et al.*, 2006; Ko *et al.*, 2006).

Although current approaches to elastography vary considerably, we can summarize the general principles of elastography as follows: (1) perturb the tissue using a quasi-static, harmonic, or transient mechanical source; (2) measure the internal tissue displacements using a suitable ultrasound, magnetic resonance, or optical displacement estimation method;