Real-Time Quantitative Elasticity Imaging of Deep Tissue Using Free-Hand Conventional Ultrasound

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Abstract. In this article an ultrasound elastography technology is reported which provides quantitative images of tissue elasticity from deep soft tissue. The technique is analogous to Magnetic Resonance Elastography in the use of external mechanical vibrations which can penetrate deep tissue. Multifrequency steady-state mechanical vibrations are applied to the tissue at the skin and tissue displacements are measured by a conventional ultrasound system. Absolute values of tissue elasticity are computed in real-time for each frequency and displayed to the physician. The quantitative elasticity images produced by the technology are validated with magnetic resonance elastography images as the gold standard on standard elasticity phantoms. Preliminary *in-vivo* data from healthy volunteers are presented which show the potential of the technology for clinical use. The system is currently being used in different clinical studies to image kidney fibrosis, liver fibrosis, and prostate cancer.

1 Introduction

Elastography has emerged as an imaging modality providing new information to the clinician about the mechanical properties of tissue [1]. It has found a place in the imaging of breast lesions [2], liver fibrosis [3], and is being investigated in many other clinical areas such as targeting of prostate cancer for biopsy and focal therapy [4].

The first generation of elastography technology was developed on ultrasound machines [5] and created images of relative elasticity of tissue. The clinician applied a manual compression with the probe to deform the tissue, and the elastography system measured the tissue strain. Under certain assumptions, the tissue strain is inversely proportional to the tissue stiffness, and therefore strain images can show the contrast in tissue stiffness. The first generation elastography

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is now available on many medium to high-end ultrasound systems under different brand names such as elastography, strain imaging, real-time elastography, etc.

The general trend in radiology towards quantitative imaging, together with the difficulties in applying the manual compression, called for more innovation and through the efforts of different groups, second generation elastography technologies were born [6, 7]. A second generation elastography technique creates quantitative elasticity images where the contrast in the image is the absolute elasticity of the tissue.

Elastography has been developed primarily with ultrasound or magnetic resonance imaging [8] as the underlying imaging device to track tissue displacements. To cause tissue displacements, different methods have been devised with mechanical transient excitation [2], mechanical steady-state excitation [8,9], and acoustic radiation force (shear wave) transient excitation [6, 7] to name a few.

The majority of the magnetic resonance imaging techniques use a steady-state mechanical excitation to image the tissue elasticity [8, 10, 11]. The idea is to measure the wavelength of the steady-state wave patterns in the tissue from which the wave speed can be estimated. The wave speed depends on the mechanical properties of tissue, and is generally higher in stiffer tissue compared to softer tissue.

The reported technology uses analogous techniques as used in magnetic resonance elastography for ultrasound elastography. A steady-state mechanical vibration is applied to the tissue while the tissue is imaged by the ultrasound. From the sequence of ultrasound images, the tissue displacements and wave patterns are computed. The local wavelength of the wave pattern is then estimated to create a map of the tissue stiffness which is displayed in real-time.

This article gives an overview of the technology and reports the most recent advances. In particular we report the first direct comparison of the technique with MRE on a standard quality assurance phantom. Steady-state excitation was first used in sonoelasticity to image tissue stiffness [12]. It has also been used before to produce MRE-type elasticity images [13]. However this is the first report of an implementation for "real-time" operation with "free-hand" conventional ultrasound. Two novel ideas which have enabled these advances are the use of a "thin-slice" consisting of a few planes for 3D data acquisition, and the fast implementation of all the image processing pipeline on a graphics processing unit (GPU). These advances are reported for the first time in this article. Based on these qualities, the technology holds promise for ultrasound guided procedures, such as biopsies, by providing additional quantitative information to the clinician.

2 Methods

The system has been implemented on a SonixTouch platform (Ultrasonix Medical Corp., Richmond, BC, Canada) (Fig. 1 (a)). Two prototype systems have been developed based on the Texo and Ulterius software development kits. A mechanical vibration source (LDS V203, LDS/B&K, Norcross, GA) has been