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Experimental three dimensional strain estimation from ultrasonic sectorial data

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Abstract

Most of the studies devoted to elastography are focused on the estimation of the axial component of the strain. However when subjected to any load, whatever the direction, soft biological media deform in the three spatial dimensions. The aim of our work is to build a three dimensional strain mapping from data acquired with a 3D clinical sectorial probe.

The estimation of radial strain is based on the estimation of local scaling factors. A method of cross-correlation of interpolated signals between adjacent radiofrequency lines was used to estimate the angular displacement and strain. For the sectorial strain estimation, the same displacement estimation technique has been implemented. The method has been tested on experimental data acquired on calibrated phantoms and compared to simulation.

Keywords: Elastography; Axial; Lateral and elevational strain estimation; 3D sectorial probe

1. Introduction

Elastography is an imaging modality that provides insight into the elastic properties of biological tissues by applying a small axial uniform compression, and imaging the resulting local strain. Until recently, only the axial and lateral strain components have been estimated and used to produce a strain image (axial and lateral elastogram). However, motion in tissue occurs in three dimensions. Therefore, estimation of motion in three directions is imperative in order to provide full information on the mechanical properties of tissue. Recently we discussed the simultaneous estimation of both axial and lateral motions using an accurate tracking method based on correlation [5]. In this paper the same method is applied in all three dimensions in order to estimate three normal strain components, i.e. axial, lateral and elevational (out-of-plane) components.

The research currently undertaken for 3D ultrasound acquisition tends to develop two dimensional arrays of piezoelectric elements. Still at the experimental stage, they make it possible to image a volume without sensor motion. The realisation of these array, however, encounter technological difficulties.

Currently, 3D acquisitions are performed plane by plane with traditional, linear or sectorial arrays. These measurements can be made according to different strategies, but in a general manner they are done by translation or rotation of the piezoelectric sensor elements or of the ultrasonic beam. In elastography, when the probe is moved in translation, the compression in each scanning plane would involve different boundary conditions and thereby different motion fields, complicating the elevational tracking. The most adapted solution for elastography will be thus to acquire data through the rotation of piezoelectric elements while keeping the probe motionless. The 3D volume consists of N 2D planes, each one being formed by L ultrasonic RF lines. The digitized ultrasonic lines contain S samples.

Using a three dimensional finite-element simulation, Konofagou [4] has shown that all three displacement vectors can be estimated using a 2D arrays.

In this paper, 3D strain distributions are studied experimentally in a phantom with a stiff inclusion, from

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ultrasound data using a rotating clinical sectorial probe which provides a 3D volume. The geometry of the acquisition is spherical; each sample is localized with 3 co-ordinates (two angles and a distance).

The compression was axial while the direction of propagation of the imaging pulse is radial. We denote u_r, u_a and u_s the displacements in various directions: radial (along the ultrasound beam), angular (perpendicular to radial direction in the scanning plane) and sectorial (perpendicular to the scanning plane) respectively.

The proposed method enables to estimate the three displacement components, radial, angular and sectorial for each imaging plane of the volume. Thereby, by projection, we calculate the three orthogonal displacement components in cartesian co-ordinates: axial, lateral and elevational. They can be used to estimate the normal as well as shear strain components that fully characterize the 3D normal strain tensor given by

$$\varepsilon = \begin{bmatrix} \varepsilon_{zz} & \varepsilon_{zx} & \varepsilon_{zy} \\ \varepsilon_{xz} & \varepsilon_{xx} & \varepsilon_{xy} \\ \varepsilon_{yz} & \varepsilon_{yx} & \varepsilon_{yy} \end{bmatrix}$$

where $\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$ and $i, j = x, y, z$ and x, y, z denotes the co-ordinate in the lateral, elevational, and axial directions respectively.

2. Material and methods

The estimation of the radial deformation is based on the estimation of the local scaling factors [1]. The method first selects adaptively corresponding segments in the pre- and post-compression echo signals; then the scaling factor is estimated by iterative variation until reaching the zero of the phase of the complex cross-correlation function of the corresponding analytic signals. This is, in practice, performed by dichotomy.

Since most clinical ultrasound transducers have a small number of channels, the sampling in the lateral direction is often not sufficiently high to allow precise lateral tracking. We have therefore implemented the interpolation method developed by Konofagou and Ophir [3], for angular displacement estimation. It tracks the RF (radio frequency) pattern of a single RF line segment in the lateral direction. Unlike the 2D kernel techniques, this technique allows to obtain displacement estimates in the lateral direction with high tracking resolution. This method has been improved by stretching locally the RF lines by the adapted radial computed strain. The algorithm is composed of three steps. At first, RF lines have been locally stretched. Secondly, more RF lines between adjacent original post-compression lines have been generated using Spline interpolation. Finally, the cross-correlation between small segments of each pre-compression RF line with segments of RF lines on the same lateral level generated via interpolation is processed. The angular displacement is indicated by the location of the maximum of the cross-correlation function.

A least-square strain estimator (LSQSE) has been used for lateral deformation estimation [2]. It has been shown that the use of LSQSE methods reduces the amplification noise due to the gradient operation. For the sectorial strain estimation, an interpolation and tracking method, similar to the one used for angular tracking is applied.

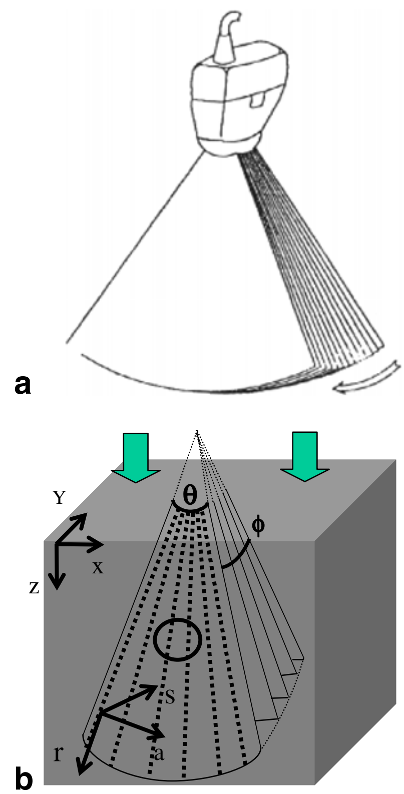

Fig. 1. (a) 1D array rotating over the elevational angle ϕ. (b) Geometry of acquisition: θ is the angle of RF signals in the scanning plane. r, a, s denote radial, angular and sectorial directions, respectively.x, y, z denote lateral, axial and elevational directions respectively.

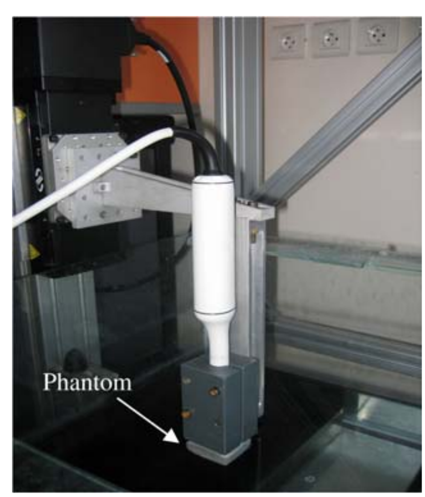

Fig. 2. Photography of the experimental set-up including the probe and the compression plate.