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● *Original Contribution*

A 3-D REGION-GROWING MOTION-TRACKING METHOD FOR ULTRASOUND ELASTICITY IMAGING

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Abstract—A 3-D region-growing motion-tracking (RGMT) method for ultrasound elasticity imaging is described. This 3-D RGMT method first estimates the displacements at a sparse subset of points, called seeds; uses an objective measure to determine, among those seeds, which displacement estimates to trust; and then performs RGMT in three dimensions to estimate displacements for the remaining points in the field. During the growing process in three dimensions, the displacement estimate at one grid point is employed to guide the displacement estimation of its neighboring points using a 3-D small search region. To test this algorithm, volumetric ultrasound radiofrequency echo data were acquired from one phantom and five *in vivo* human breasts. Displacement estimates obtained with the 3-D RGMT method were compared with a published 2-D RGMT method *via* motion-compensated cross-correlation (MCCC) of pre- and post-deformation radiofrequency echo signals. For data from experiments with the phantom, the MCCC values in the entire tracking region of interest averaged approximately 0.95, and the contrast-to-noise ratios averaged 4.6 for both tracking methods. For all five patients, the average MCCC values within the region of interest obtained with the 3-D RGMT were consistently higher than those obtained with the 2-D RGMT method. These results indicate that the 3-D RGMT algorithm is able to track displacements with increased accuracy and generate higher-quality 3-D elasticity images than the 2-D RGMT method. (E-mail: wangyuqi1981@gmail.com) **© 2018 World Federation for Ultrasound in Medicine & Biology. All rights reserved.**

Key Words: **Motion tracking, Displacement estimation, Elasticity imaging, Region growing, 3-D elastography, 3-D strain image.**

INTRODUCTION

Ultrasound strain elastography (Hall et al. 2003; Odonnell et al. 1994; Ophir et al. 1991) (SE) is a non-invasive method used to estimate the relative stiffness of biological tissues. Changes in tissue elasticity often correlate to pathologic evolution of many diseases (Fung 1993). SE has been successfully applied to non-invasive differentiation of breast lesions (Barr et al. 2015; Burnside et al. 2007; Hall et al. 2003) and is now available on most commercial ultrasound imaging systems using 1-D or 1.25-D linear array transducers to form 2-D strain images. Block matching is a common approach to track displacements between pairs of radiofrequency (RF) echo signal frames (Jiang and Hall 2009; Odonnell et al. 1994; Zhu and Hall 2002). To obtain displacement (and strain) estimates within a region of interest (ROI), the simplest approach is to perform an exhaustive (block-matching) search.

Because breast tissues can roughly be assumed to be a continuum, internal displacement fields resulting from an external load should be reasonably continuous. Because of this tissue continuity assumption, a cohort of guided-search motion-tracking methods have been reported in the literature (Jiang and Hall 2007; Zahiri-Azar and Salcudean 2006; Zhu and Hall 2002). More specifically, a guided-search motion-tracking method assumes that a displacement vector at one location can be used to guide the block-matching search in its immediate neighboring points. This strategy reduces the computational cost by limiting the search range. The guided-search strategy also makes large ("peak hopping"; Walker and Trahey 1995) tracking errors less likely (given good initial displacement estimates). Early guided-search motion-tracking algorithms had preferred guidance directions, for example, axial guidance (Zhu and Hall 2002), lateral guidance (Jiang and Hall 2007) and diagonal guidance (Zahiri-Azar and Salcudean 2006). The problem with these guidance strategies is the displacement estimate error accumulation resulting from those errors providing bad guidance during the guided-search process. Chen

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et al. (2009) suggested that, instead of a systematic directional search, the priority of search guidance should depend on the quality of echo signal matching, and this strategy has significantly reduced displacement estimate error accumulation (Zhu and Hall 2002). However, this strategy can also be influenced by the accuracy of the initial displacement estimates (known as *seeds*). Fleming et al. proposed a robust regularized displacment estimation method in which displacement was first estimated for one most robust RF-line (called seed RF-line) by optimizing a cost function that incorporates the RF amplitude similarity and displacement smoothness *via* dymamic programming, and then propagated in other directions throughout the entire image (Fleming et al. 2012; Rivaz et al. 2008a, 2008b). Jiang and Hall (2011) improved the quality-guided search by setting strict criteria for seed selection, thereby improving the tracking outcome.

Although those studies found that the guided search can effectively eliminate some large tracking errors using 2-D ultrasound data, improved motion tracking alone cannot completely overcome echo signal decorrelation induced by out-of-plane motion (perpendicular to the 2-D imaging plane) (Bharat et al. 2008; Bilgen and Insana 1997). The 3-D volumetric whole-breast ultrasound systems (*e.g.,* Siemens Acuson ABVS and GE Invenia ABUS) now available present an excellent opportunity for performing 3-D volumetric SE. The perceived advantages of a 3-D breast SE system include the following: (i) motion-tracking errors resulting from the presence of out-of-plane motion can be reduced, and (ii) viewing the full breast lesion in three dimensions (multiple parallel, perpendicular or arbitrary planes, not just the easiest plane to obtain a strain image) may further aid diagnostic accuracy. To track 3-D displacements, a 2-D region-growing motion-tracking (RGMT) method was previously reported (Wang et al. 2017), in which high-quality seed selection and subsequent region growing were limited to a single plane while the motion tracking was performed in three dimensions. In other words, region-growing motion tracking was first performed in one plane to obtain 3-D displacement vector fields, and then the displacement estimates in that plane were used to guide displacement estimation of its adjacent plane(s).

The 2-D region growing used in the 2-D RGMT method is constrained within an imaging plane and, therefore, may be "sub-optimal" in the practical sense. The primary goals of this study were twofold. First, a framework/strategy termed *3-D RGMT* is described that extends the quality guided search (Chen et al. 2009) into a 3-D search in arbitrary directions (not limited by the direction of acquisition of consecutive 2-D planes). Second, the performance of 3-D RGMT was compared with that of the 2-D RGMT approach using 3-D ultrasound data acquired from a tissue-mimicking phantom and *in vivo* breast tissues containing lesions. Given signal decorrelation and anatomic discontinuities present in the breast, we expect that some large tracking errors may be avoided if high-quality 3-D motion-tracking guidance can be provided.

METHODS

The core concept of this motion-tracking method is built on several previously published guided-search algorithms in two dimensions (Chen et al. 2009; Jiang and Hall 2011; Wang et al. 2017). Hence, emphasis here was given to new developments in three dimensions. Three-dimensional RGMT was performed on a pair (a pre-deformation and a post-deformation) of volume RF echo signal data. In the pre-deformation data, a sparsely and evenly distributed set of RF sample points within a 3-D region of interest (ROI) was selected as the tracking ROI. The aim of the 3-D RGMT was to estimate displacements of the points within the tracking ROI.

Our description below starts with some basic definitions used in the motion-tracking algorithm, followed by implementation details. These basic definitions include the neighboring point (NP), known-displacement point set, interior point (IP) set and boundary point (BP) set. More details can be found in Appendix A. In the framework of motion tracking, our goal was to make the known-displacement point set include the entire tracking ROI. In this sense, mathematically, the motion-tracking task converts members of the unknown-displacement point set to members of the known-displacement point set.

Algorithm overview

Like other guided-search algorithms (Fleming et al. 2012; Jiang and Hall 2011), the 3-D RGMT algorithm is a two-step process. It starts with a set of highly reliable displacement estimates, called *seeds*. Then, like other region-growing algorithms (Wang et al. 2017), motion tracking proceeds by a guided search in the neighborhood of those seeds.

Step 1. Finding seeds. To initiate this algorithm, some highly reliable seeds need to be identified by meeting a set of pre-determined acceptance criteria described below. First, a sparse set of points (typically 1–2 mm apart) in the tracking ROI are randomly selected as candidates for seed centers. For each selected center point, its 6 NPs are also included in the test for that seed. An exhaustive block-matching search is performed (using normalized cross-correlation for the block-matching metric) for each of the 7 points for each candidate seed using a large 3-D search region that accommodates at least 5% local strain. The maximum (tracking) cross-correlation sum (MCCS) (Wang et al. 2017) of all 7 points is one metric for the quality of motion tracking for that seed. The maximum absolute displacement difference (MADD) (Wang et al. 2017) between the NPs and the center point (*i.e.,* the displacement