Evaluating Dermoscopic Applications for Modality Independent Elastography

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INTRODUCTION

Analysis of the mechanical properties of skin has clinical implications ranging from skin cancers to osteoporosis to diabetes mellitus, as changes to the cytoarchitecture of the skin in these pathologies have been purported to manifest as alterations in tissue elasticity. Therefore, a dermoscopic procedure geared towards uncovering functional information about the mechanical behavior of skin has potentially important diagnostic utility. Typical elastography methods such as Magnetic Resonance Elastography (MRE) and Ultrasound Elastography (USE) are dependent on the specific imaging modality for which they were developed. We have developed 'modality-independent elastography' (MIE) as a distinct methodology to be an image processing technique that conceptually relies only on the inherent pattern contained within an image and not any particular acquisition mode. The result is a reconstruction of elasticity values (i.e. Young's modulus) extracted by comparison via similarity measurements of images taken before and after an applied deformation of the tissue.

METHODS

The conceptual framework for the elastographic reconstruction involves three major components: a biomechanical model of the tissue, image deformation and comparison, and numerical optimization of image similarity. In brief, an image of a tissue of interest (*source*) is deformed by the prescribed computational model and compared against an acquired image of the same tissue in a mechanically loaded state (*target*). The deformation and comparison is repeated using systematic updates of elasticity parameters until a suitable match in image similarity is achieved in a least squares manner to satisfy a multi-resolution, non-linear optimization scheme. Because the goal is to determine a spatial mapping of tissue elasticity, this process can be classified as an inverse problem, with model-based deformation of the source image representing the forward problem. For the current version of MIE, linear elasticity with a plane stress approximation is used as the biomechanical model, the correlation coefficient as the image similarity metric, and a regularized Levenburg-Marquardt algorithm as the optimization method. The constitutive stress-strain relationship of the model is solved using finite elements with the Galerkin method of weighted residuals, and Dirichlet boundary conditions are manually selected from corresponding points in the image pair.

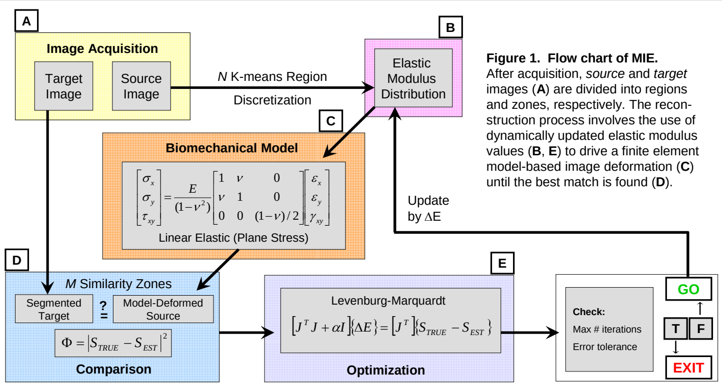

Figure 1. Flow chart of MIE. After acquisition, *source* and *target* images (**A**) are divided into regions and zones, respectively. The reconstruction process involves the use of dynamically updated elastic modulus values (**B**, **E**) to drive a finite element model-based image deformation (**C**) until the best match is found (**D**).

EXPERIMENTAL SETUP

Experiments were performed with two polyurethane phantoms that simulate surface skin lesions in order to test the ability of MIE to detect areas of differing relative elasticity. One phantom was created with a single 5-cm circular stiff inclusion embedded in the center of a 15-cm square membrane of bulk material, and the other made with two 1.5-cm inclusions situated at opposing corners. Independent material testing determined that the expected elasticity contrast was approximately 6 to 1. A permanent marker was used to impose a grid of regularly spaced lines on the membranes. A uniaxial strain of about 8 percent was applied and images obtained using a commercial webcam.

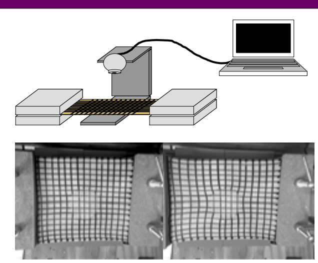

Figure 2. Top: Schematic of membrane deformation and image acquisition system. **Bottom:** Representative photographs of phantom under strain applied by device.

RESULTS

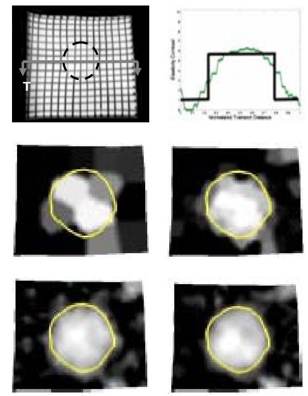

Figure 3. MIE reconstruction: single-inclusion phantom. Source image (top left) and transect of relative elasticity (top right). Reconstructions for increasing number of K-means regions: *N* = 16 (middle left), 64 (middle right), 256 (bottom left), and 400 (bottom right).

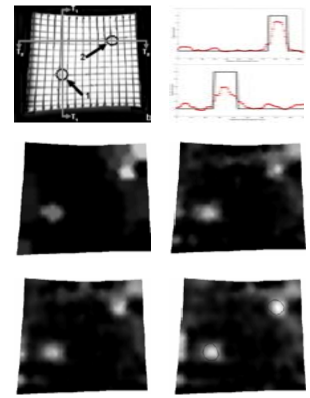

Figure 4. MIE reconstruction: dual-inclusion phantom. Source image (top left) and transects of relative elasticity (top right). Reconstructions for increasing number of K-means regions: *N* = 64 (middle left), 256 (middle right), 512 (bottom left), and 800 (bottom right).

DISCUSSION

In this study, MIE was used to detect stiff inclusions in membrane phantoms of skin in order to demonstrate possible applications towards non-invasive procedures used for evaluation of pathologies of or related to the skin. MIE reconstruction performed on the single-inclusion phantom demonstrated a successful detection of significant and relevant material inhomogeneity, and a similar result was obtained from analysis of the dual-inclusion phantom. Additionally, the use of a multi-resolution reconstruction scheme produced results with good spatial localization and suitable contrast in elasticity values and improves upon previous algorithmic approaches based on dual-grid meshing of the domain.

FUTURE STUDIES

Current ongoing research is focused on nevus evaluation with MIE as applied to images of human skin surfaces with high-resolution digital optical images. Preliminary results with a melanoma photograph under simulated deformation demonstrate the ability to detect a stiff lesion associated with a visually demarcated area.

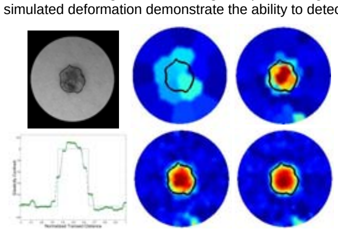

Figure 5. **Left:** MIE reconstruction of a simulated surface melanoma lesion. Source image (top left), transect (bottom left), and reconstruction progression with increasing number of regions. **Right:** Current working prototype of dermoscopic imaging system.

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