X-Ray Mammogram Registration: A Novel Validation Method

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Abstract. Establishing spatial correspondence between features visible in x-ray mammograms obtained at different times has great potential to aid assessment of change in the breast and facilitate its quantification. The literature contains numerous non-rigid registration algorithms developed for this purpose, but quantitative estimation of registration accuracy is limited. We describe a novel validation method which simulates plausible mammographic compressions of the breast using an MRI derived finite element model. Known 3D displacements are projected into 2D and test images simulated from these same compressed MR volumes. In this way we can generate convincing images with known 2D displacements with which to validate a registration algorithm. We illustrate this approach by computing the accuracy for a non-rigid registration algorithm applied to mammograms simulated from three patient MR datasets.

1 Introduction

In order to determine the presence or classification of breast cancer from x-ray mammograms, radiologists routinely compare images. This comparison may be made with mammograms obtained on a previous occasion, with alternate views of the same breast obtained during the same screening visit, or with the same view of the other breast as a means of determining any asymmetry that might be present. Clearly this comparison helps to confirm or refute the radiologist's appraisal of the disease and may enable an assessment of change and hence disease progression to be made.

While there have been several proposed methods for registering x-ray mammograms they are all generally flawed as they fail to take into account the complex 3D displacements of anatomy that contribute to the changes seen on the conventional x-ray projection of the compressed breast. In other words the applied transformations are diffeomorphic in the 2-dimensional plane, specifying a one to one correspondence between points in the registered images. In addition quantitative validation, when performed, is most commonly limited to the error associated with matching particular lesions identified by a clinician. This

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approach is limited to the region of the lesion and dependent upon the visibility of the lesion in each view.

We propose a new method for evaluation of strategies for establishing this correspondence which uses 3D displacements obtained from computational biomechanical models of the breast. Our method simulates plausible mammographic compressions of the breast using an MRI derived finite element (FE) model. The resulting 3D displacements are then projected into 2D. X-ray mammograms are simulated from these same compressed MR volumes, generating convincing images with known 2D displacements with which to perform a registration validation. To illustrate this approach we compute the accuracy of non-rigid registrations of mammograms simulated from three patient MR datasets. The registration algorithm evaluated has previously proved accurate in 3D MR breast registrations [1].

We intend to use this method to aid development of new registration algorithms.

2 Methods

2.1 An MR Derived FE Model of Breast Compression

At the heart of our validation method is data describing the typical relative displacement of breast tissue caused by compression applied during routine x-ray mammography on separate occasions. This data was obtained using a FE model of the breast, constructed from segmented MR images and implemented using the FE software package ANSYS [2].

The FE models consisted of between 40,000 and 70,000 10-noded tetrahedral elements. Plate compressions were simulated by applying surface displacement boundary conditions, with displacements only specified in the direction perpendicular to the plates. This allows slippage along the plates to occur. Nodes adjacent to the pectoral muscle were constrained to have zero displacements as in [3]. All other nodes were allowed to move freely. Fatty, glandular and tumourous tissues were modelled as homogeneous, isotropic materials with linear elasticities of 1kPa and 1.5kPa, respectively, in accordance with tests extending the work reported in [4, 5]. Elasticity of tumorous tissue was varied between 3.6kPa and 10.8kPa to produce realistic variation in the data. In comparison to previous studies, our FE configuration was selected based on the accuracy of linear, non-linear and hyperelastic models to predict the location of internal breast structures after a 20% in-vivo compression for two volunteers [5]. This evaluation included models covering the wide range of reported elastic properties [6, 7] and variations to it [8, 9]. Linear models performed as well as non-linear models for these deformations. The three tissue types (fat, glandular and tumourous) were manually thresholded from the MR volume (after correction for inhomogeneities), and implausible regions resulting from this segmentation were removed in a subsequent manual processing step. A Poisson's ratio of 0.475 was chosen to allow for volume changes due to reduced blood volume as a result of the compression.

Cranio-caudal compressions for different patient visits were simulated by varying both the percentage compression, α, and the angle from the cranio-caudal axis