Local Rigid and Volume preserving deformable registration method with applications to liver MR data

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Introduction: Image registration is an invaluable tool for analyzing the impact of tumor therapies within the breast, liver, and brain. Images acquired at different times invariably result in changes in the patient's orientation and position. Registration methods re-orient and re-sample the images to allow for more direct analysis between or among images. Non-rigid registration offers more flexibility, but may result in tumor size and shape changes. In one study, a tumor volume loss of up to 78% was shown in breast MR images [1]. In order to address these issues, volume-preserving non-rigid registration methods have been proposed [1-6]. However, some volume changes occur due to changes in air or fluids within the patient. Partial volume-preserving non-rigid registration methods allow for optimal spatial correlations [1-4,6] by demarcating regions of local rigidity or volume preservation within the image. Constraints are enforced either within the cost function [1,3,4,6], during regularization [2], or integration of a divergence-free constraint in a separate step [5]. The limitations in these approaches are that a specific registration method or cost function must be used. We present an approach that modifies the final deformation field, resulting in a locally rigid or volume preserving registration that is both easy to implement and applicable to almost all existing registration methods. Initial results are presented in comparison to a deformable registration [7].

Method: The method is easy to implement on almost all existing registration methods and only requires access and modification of the deformation field prior to its application on the moving image as shown in Figure 1. This method modifies the final registration field to ensure that the transform is either locally rigid or locally volume preserving. Given the resultant deformation field ϕ_F of a registration that maps the space of a moving image I_2 into the space of a fixed image I_1, we modify ϕ_F to be locally volume-preserving or rigid based on a mask ***M***. Regions are marked as either rigid, volume-preserving, or untouched within ***M***. Ideally, a tumor region would be defined within this mask. Two types of modifications are performed on ϕ_F. For locally rigid constraints, a rigid transformation is fit to the marked subset of the deformation field defined within the mask. First, the *Singular Value Decomposition* (SVD) of the covariance matrix is obtained from the rigid-defined points within the mask and their mapped locations through the deformation field. Next, the orthogonal component of the SVD results in a rigid transform estimation of the given points. This transform is then used to modify the region of the deformation field. For local volume-preservation, a method similar to [5] is used. A locally divergence-free vector field ensures volume preservation. A modification of the Poisson equation used to project the gradient is possible such that a smooth spatially varying term based upon the mask is used. Since the Hodge decomposition is orthogonal, the "divergence-free" component can be used to replace portions of ϕ_F. Finally, smoothing about the perimeter of the masked regions via a Gaussian filter is performed to ensure smooth transitions. The modified deformation field ϕ_M is then applied to the moving image instead of ϕ_F.

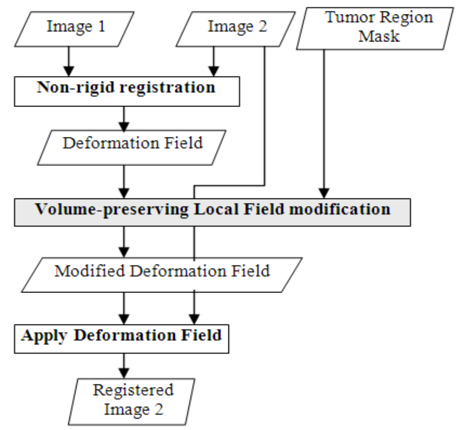

Figure 1: Flowchart of the proposed method. The deformation field is modified before application, making it applicable to almost all registration techniques.

Results: MR Liver datasets of patients taken 4 months apart where registered. A T1 pre-contrast image was registered to a T1 Arterial image using the method in [7] with a Local Cross-Correlation (LCC) cost function. The resultant images and deformation fields were visualized are shown in Figure 2. A spherical enhancing lesion was inserted into the arterial T1 image. Standard registration results in distortion with a loss of volume. The proposed method creates little or volume loss. The corresponding deformation fields were colored based upon the divergence. Regions of positive or negative divergence were colored blue and orange respectively, while regions of low or no divergence (*below 1.0*) where colored green. The additional computation time required was about 3 seconds with the majority occupied by the volume-preserving field computation. Locally rigid and volume-preserving regions were achieved by deformation field modification.

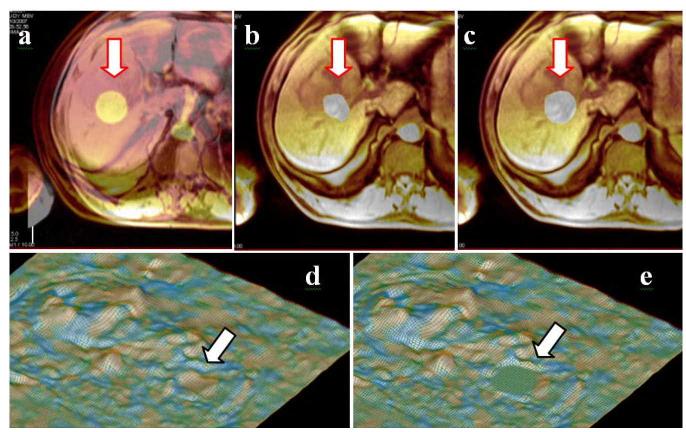

Figure 2: Comparison of registration results. Overlay of two images with spherical enhancing lesion before registration (a), after registration (b), and after proposed method (c). Comparison of deformation fields without (d) and with (e) the proposed method.

Conclusion: A method to perform locally rigid and volume-preserving non-rigid registration based on given mask(s) was presented. Existing methods incorporate limitations into the cost function or regularization step to ensure volume preservation or rigidity constraints. We proposed a method that modifies the final deformation field for easy incorporation into any existing registration frameworks. The method was demonstrated on T1-weighted liver MR data. Multiple masks are possible and the method is especially useful for rigid structures like bones or the rib cage. Further studies on additional datasets are planned to better quantify the volume of lesions with the proposed method.

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