EVALUATION OF A THORACIC ELASTIC REGISTRATION METHOD USING ANATOMICAL CONSTRAINTS IN ONCOLOGY

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*Abstrac*t-**The aim of our work is to improve data analysis in thoracic oncology applications by means of non-rigid registration of CT and PET images. A Mutual Information-driven transformation using B-Spline Free-Form Deformations performs the alignment of the image volumes. Special constraints relying on hierarchically identifying corresponding structures in both modalities have been added to guarantee the convergence towards an optimal registration**.
***Keywords* - Multimodality registration, constraints, oncology**

I. INTRODUCTION

PET (Positron Emission Tomography) images acquired with 18-FDG tracer are becoming the most used image modality in oncologic applications. This imaging technique has been shown to provide high sensitivity and specificity for the detection of primary and metastatic cancers not visualized by classical morphological acquisitions. However, it provides little information on the exact locations of the increased uptake. On the other hand, CT provides accurate details of the size and shape of lesions, but indicates nothing about lesion malignancy. Consequently, combining information from these two modalities would have a significant impact in improving medical decisions for diagnosis, therapy and treatment planning [1].

Integrating data from different imaging modalities requires geometric alignment or registration to compensate for differences in field of view, patient positioning and other acquisition parameters. Several difficulties arise from the different acquisition protocols and physical properties of the modalities to register, such as different sizes, resolutions, scan times or patient position. In our particular case, these problems specially worsen due to the elastic nature of the imaged region.

In many cases a satisfactory solution can be found by using rigid or affine registration. However, in thoracic and abdominal applications, due to local deformations and the high variability of acquisitions, a non-rigid approach with significantly more degrees of freedom is needed.

To the best of our knowledge, little effort had been made in the past to register very deformable anatomical regions such as the thorax and abdomen. However, several recent research works aim at registering these regions. One elegant solution to multimodality chest image registration was proposed by Mattes [2]. He models deformations with cubic B-Splines defined by placing a regular grid of control points over the volume and then modified by moving these control points. Mutual information, proposed by Viola [3] is used to measure image similarity.

Our work is based on an evolution of this technique used by Rueckert et al. [4] for the non-rigid registration of contrast-enhanced breast MRI. The results indicate that this registration algorithm is much more able to recover the motion and deformation of the breast than rigid or affine registration algorithms. A drawback of this method was the excessive power of the transformation, that tended to converge towards local minima of the similarity criterion unless a very accurate initialization was provided.

One way to provide such initialization is through extraction of anatomical references. In this paper we propose a method in which, by turning the initialization procedure into almost an elastic registration of its own, we are able to effectively apply an accurate Mutual Information registration technique to areas with severe deformations such as the thorax.

II. METHODOLOGY

A. Registration framework

Our goal is to improve data analysis in various oncology applications by means of non-rigid registration of CT and PET images. A non-rigid transformation using B-Spline Free-Form Deformations (FFD) has been chosen to perform the registration of the image volumes. In this technique, deformations of the object volume are achieved by tuning an underlying mesh of control points. A B-Spline based FFD can be written as a 3D tensor product of one-dimensional cubic B-Splines. Let Φ denote an uniformly spaced grid of $n_x \times n_y \times n_z$ control points $\phi_{i,j,k}$ with a spacing of δ, where $-1 \le i < n_x-1$, $-1 \le j < n_y -1$, $-1 \le k < n_z -1$. Then, the elastic transformation for each image point x,y,z is computed as:

$$T_{elast}(x,y,z) = \sum_{l=0}^{3}\sum_{m=0}^{3}\sum_{n=0}^{3} B_l(u)B_m(v)B_n(w)\phi_{i+l,j+m,k+n}$$

Here, i, j, and k denote the index of the control point cell containing (x,y,z), and u, v, and w are the relative positions of (x,y,z) in the three dimensions, B_0 through B_3 being 1D cubic B-Splines. The displacement of the control points is found by optimizing a similarity measure, a function that evaluates the quality of the registration for a given set of transformation parameters.

Due to the non-functional relation between CT and PET values we use normalized mutual information (NMI), an information theoretic measure that expresses how much information from an image A is contained in another image B:

$$NMI(A,B) = \frac{H(A)+H(B)}{H(A,B)},$$

where $H(A)$ and $H(B)$ are the marginal entropies of images and $H(A,B)$ is their joint entropy, which is calculated from the joint histogram of A and B.

The main drawback of this method is that it tends to get trapped in local minima of the similarity function. We overcome this limitation by providing an initialization of the deformation field, based on structural information extracted from the images.

B. Initialization procedures based on segmentation of anatomical structures

Detection of anatomical features is one of the most intuitive ways to register medical images, and has been used successfully in a wide variety of applications. However, this kind of technique has a serious drawback since any errors introduced by the segmentation will affect the accuracy of the final registration. On the other hand, using one of this fast, reliable methods can provide a good initialization and a set of constraints for the non-rigid transformation, leaving the Mutual Information to deal with any inaccuracies stemming from the segmentation faults.

A good trade-off between speed and quality of segmentation can be achieved by hierarchically applying thresholding operations to the images along with mathematical morphology, using the information obtained from the most distinct features to constrain the segmentation of subtler ones. The idea of progressive structure recognition was already used in [5] for cerebral tissue classification.

The automatic thresholding is performed by a k-means algorithm. Two dimensional vectors for the voxels are used for the PET image, to take advantage of the information contained both in the transmission and attenuation images.

Once the visible structures have been segmented and set in a common metric space, their contours are extracted and brought into rigid registration by means of the Iterative Closest Point algorithm (ICP). With the segmented structures thus aligned, the distance map computed for the ICP algorithm provides an efficient, if primitive, estimation of the non-rigid transformation between the surfaces of each pair of organs that can be used to initialize the free-form deformation. Given this initialization, the speed and accuracy of the subsequent mutual-information based registration is significantly increased.

III. VALIDATION

Despite no gold standard parameter set being available, quantitative measures of the performance of the registration, such as NMI or distances among segmented structures can be used. The amount of overlap for four pairs of registered images after different initialization procedures is plotted in Fig. 1.

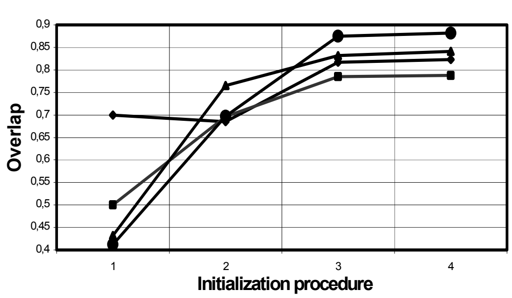

Fig.1. Overlap measure of registration quality.
1-User initialization. 2-Automatical centering and resizing.
3-ICP rigid initialization. 4-Non-rigid initialization.

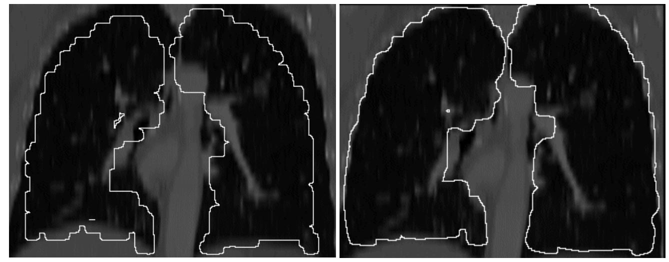

Fig. 2. Lines show lung contours extracted from registered PET image. Left: Without anatomical constraints. Right: With initialization procedure.

A significant improvement when the system is initialized with the rigid transformation provided by ICP instead of manually selecting the region of interest can be appreciated. However, non-rigid initialization with the deformation field obtained by generalization of the surface differences does not improve the overall result as much as was expected. We suppose this to be the effect of local differences in the surfaces of the extracted organs due to the nature of the acquisition modalities. Visual inspection of lung contours extracted from the registered PET image superimposed to the original CT confirms the graphic results, as seen in Fig. 2.

IV. DISCUSSION

The results presented in this paper indicate that our method can provide a reliable tool for data analysis in thoracic oncology applications. The non-rigidity in the imaged regions is effectively modeled by means of a Free Form Deformation, and satisfactory registration results can be obtained by minimizing a Normalized Mutual Information criterion, given a good enough initialization. A progressive classification method has been proposed to provide such an initialization.

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