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Computing a Uniform Scaling Parameter for 3D Registration of Lung Surfaces

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Abstract. A difficulty in lung image registration is accounting for changes in the size of the lungs due to inspiration. We propose two methods for computing a uniform scale parameter for use in lung image registration that account for size change. A scaled rigid-body transformation allows analysis of corresponding lung CT scans taken at different times and can serve as a good low-order transformation to initialize non-rigid registration approaches. Two different features are used to compute the scale parameter. The first method uses lung surfaces. The second uses lung volumes. Both approaches are computationally inexpensive and improve the alignment of lung images over rigid registration. The two methods produce different scale parameters and may highlight different functional information about the lungs.

Keywords: Registration, Medical Imaging, Lung Alignment

1 Introduction

Lung registration is becoming an important tool in the medical community to help in the analysis and diagnosis of pulmonary disease [1–4]. Registration methods range from rigid approaches with few transformation parameters [1] to elastic approaches with a number of parameters on the order of the image size [4, 5]. The latter approaches generally are iterative methods that take a much longer to compute and may converge to suboptimal solutions. They therefore often use an approach with few parameters as a first step to compute an initial alignment. We here propose such an approach. In particular, we developed and compared two methods for aligning lungs in repeated CT studies based on rigid registration and

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uniform scaling. Either method may be used to estimate an initial set of transformation parameters for non-rigid registration algorithms. The first method uses lung surfaces to estimate a scale parameter for optimal rigid alignment; the second uses lung volumes.

2 Methods

Given 3D coordinates $\mathbf{x}$ in source scan A and 3D coordinates $\mathbf{p}$ in target scan B, the transformation

$$\mathbf{x} = s\mathbf{R}\mathbf{p} + \mathbf{x_0} \tag{1}$$

maps $\mathbf{p}$ into $\mathbf{x}$, where $\mathbf{R}$ represents the three parameters of a rotation and s represents a uniform scale parameter. Vector $\mathbf{x_0}$ describes the 3D translation between $\mathbf{x}$ and $\mathbf{p}$. We used Horn's technique for finding a rotation matrix R and translation vector $\mathbf{x_0}$ for computing an optimal rigid alignment [6]. In our case, the optimal alignment that minimizes the least-squares error between corresponding points on the lung surfaces, which were segmented as described by Betke et al. [1]. Correspondence was established based on the Euclidean distance of between point pairs [7].

Our first approach for computing the scale parameter s, based on Horn's work [6], uses the mean length of vectors from the lung surfaces to the centroid of the lungs. Given the centroid $\overline{A} = \frac{1}{n}\sum_{i=1}^{n} A_i$ of lung surfaces, where A_i represents a point on the lung surfaces, a vector from the centroid to a point on the lung surfaces is defined as $A'_i = A_i - A$. Scale parameter s_c can be determined by computing the mean length of the vector from the lung centroid to all voxels on the lung surfaces as follows

$$s_c = \sqrt{\frac{\frac{1}{n}\sum_{i=1}^{n}(B'_i)^2}{\frac{1}{m}\sum_{i=1}^{m}(A'_i)^2}}, \tag{2}$$

where m and n are the number of points on the lung surfaces of scans A and B respectively. A scale factor computed in this manner can be determined independently of the choice of the rotation parameter and provides a symmetric result in the sense that it is optimal with respect to the transformation of scan A into B as well as the transformation of scan B into A.

Another approach for computing the scale parameter is to use the relative volumes of the lungs. Our proposed algorithm approximates lung volumes by counting the number of voxels in the 3D segmented scan of the lung and then multiplying each voxel by the corresponding physical unit related to a particular CT scan. The scale parameter s_v is then computed using the ratio of the two lung volumes as follows:

$$s_v = \sqrt[3]{\frac{Volume(B)}{Volume(A)}}. \tag{3}$$

3 Results

We tested our methods using four CT scans of the lungs of a sheep at different inspiration levels (Figure 1 top). Mechanical ventilation was used to control inspiration during imaging, specifically by the setting of a positive end expiratory pressure (PEEP). The resolution of the scans was 0.7 mm × 0.7 mm × 10 mm and the number of images per scan ranged from 31 to 33. We computed the scale parameters s_c and s_v using the scan taken at PEEP 10 as the source scan and scans taken at PEEP 10–25 as target scans. The results are summarized in Table 1. The volume method produced larger scale parameters than the lung surface approach. Visual inspection of the transformed lung surfaces was also performed. Figure 1 shows wire frame models of the lung before and after registration with scale parameter s_c computed by our lung surface approach. The resulting alignment of the lung surfaces is significantly better than the original alignment.

Table 1. Results of Computing Scaling Parameter at Different Inspiration Levels using PEEP 10 as the Source Scan

Target Scan PEEP	10	15	20	25
Number of Voxels	277,801	301,726	339,026	369,437
Volume (liters)	1.36	1.48	1.66	1.81
s_v	1	1.028	1.069	1.100
s_c	1	1.005	1.067	1.071

4 Discussion and Conclusions

We propose two methods for registering lungs in repeated CT studies by using a uniform scaling parameter. Our results provide a proof of concept that both the volume method and the lung surface method improved the alignment of scans over rigidly registered scans. Although the resulting transformation provides a close match between two lung surfaces, a local registration may be required for a more accurate image alignment due to non-uniform expansion of the lung during inspiration. The use of a uniform scaling parameter should provide a better initialization for non-rigid lung registration algorithms [4] than rigid registration provides. In future work, we intend to analyze the alignment accuracy of the proposed approaches with respect to landmarks in the lung.

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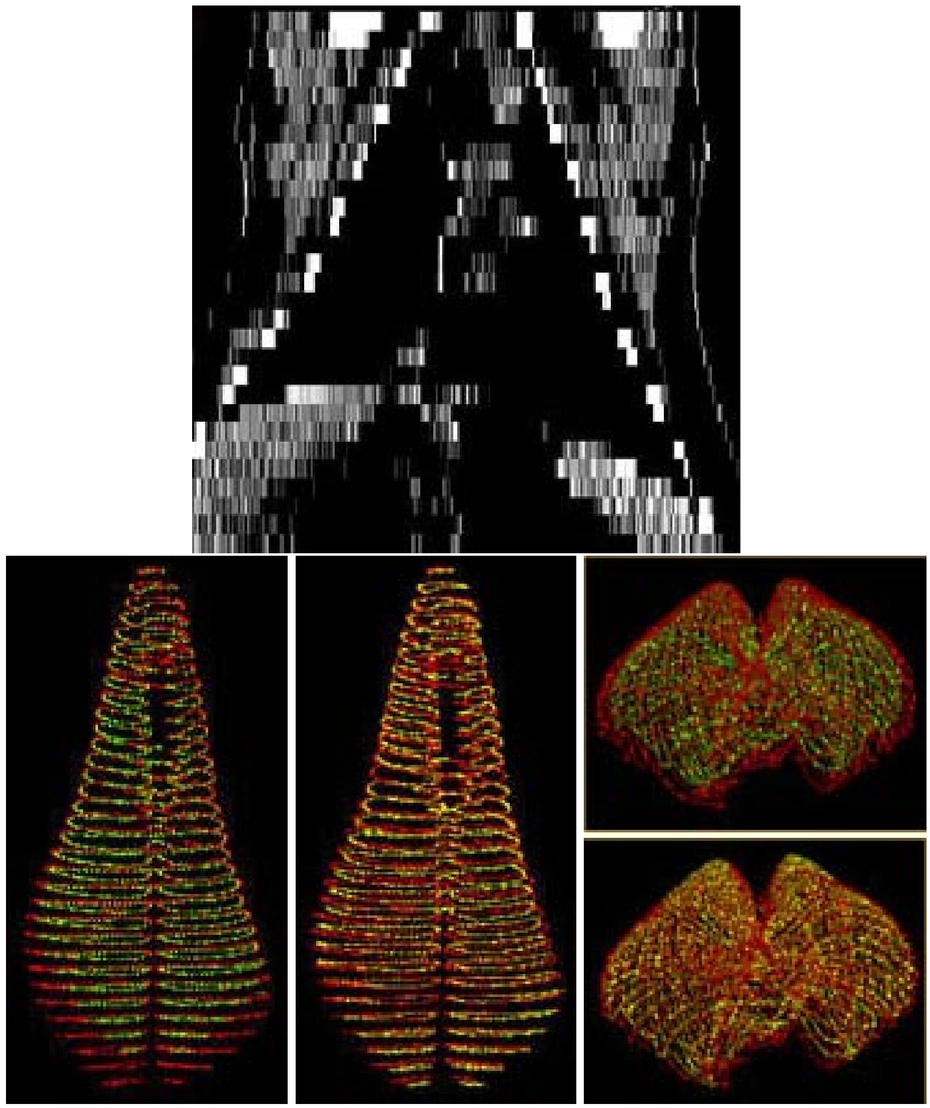

Fig. 1. Top: Coronal view of the sheep lungs. Bottom Left: Coronal view of wire models of lungs (green at PEEP 10, red at PEEP 25) are shown prior to transformation. Bottom Middle: Wire models after scale parameter s_c has been applied to the previously green wire model, now drawn in yellow. Bottom Right: Axial views of wire models of lungs (green at PEEP 10, red at PEEP 25) are shown before (top) and after (bottom) the application of scale parameter s_c.