Interstitial lung disease progression in CT: registration algorithm evaluation

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Objectives

The follow up of disease progression, of patients who suffer from Interstitial Lung Disease (ILD) is one of the most challenging problems for image based quantification systems in CT. Since visual estimation of disease extent by experts is time consuming, the development of accurate and reproducible image analysis tools, adapted to volumetric datasets, for the automated estimation of ILD extent and progression is an emerging need.

Automated estimation of ILD extent and progression involves comparison between derived disease extend between scans obtained at different time instances (follow up scans). The main image analysis method behind this step is lung volume registration. Lung volume registration is important ensure that any measured volume change between follow up scans is caused by ILD pattern change and not by segmentation error, intrinsic variability in an algorithm caused by its initialization, or the imprecision in the segmentation algorithm caused by, for instance inconsistent imaging protocols, the patient's breathing or positioning during CT scanning, i.e. registration errors.

Up to now, several registration techniques have been developed in order to register lung CT Volumes. However most of them are focused on lung field volumes with normal appearance, or lung volumes with presence of focal abnormalities while the only study reporting on ILD progression and response to therapy has gained attention with only one study has been applied on 2-D data sets.

The objectives of this study are:

(i) the evaluation of the lung field registration techniques and

(ii) the selection of registration optimal parameters, in case of ILD affected volumetric data.
Materials and Methods

Materials

Data Set: A pilot clinical data set was acquired consisting of 4 pairs of MDCT scans corresponding to 4 patients diagnosed with IP secondary to connective tissue diseases, radiologically manifested with ground glass, at two different times, abstaining in time approximately two years. MDCT scans were obtained with a Multislice (16x) CT (LightSpeed, GE), in the Department of Radiology at the University Hospital of Patras, Greece. Acquisition parameters of tube voltage, tube current and slice thickness were 140 kVp, 300 mA and 1.25 mm, respectively. The image matrix size was 512x512 pixels with average pixel size of 0.89 mm.

Artificially Warped Data: Four (4) sets of artificially warped data were created, applying a thin-plate Kernel-Spline transformation to a each dataset, originating from ILD affected patients. One hundred (100) random landmark points were generated automatically in the baseline scan and matched in the follow-up scan. A thin-plate-spline model was created using the 100 pairs of matching points. Using this thin-plate-spline model and linear interpolation, the baseline image was warped to create an image with the same image size and spacing as the follow up scan.

Methods

Registration. A block diagram of the proposed evaluation methodology, is depicted in Fig. 1 on page 6, while a block diagram of the multiresolution registration approach utilized is provided in Fig. 2 on page 6. The software that was used for the implementation of registration algorithms was Elastic v4.5, based on ITK.

Parameters. In all cases multiresolution registration was used. Four (4) levels of resolution were utilized, while the maximum number of iterations for the first three levels was set at 500 and for the last one at 300. For the first three level, rigid and affine transforms utilized, while a third order B-spline transform used for the last resolution level. For each of 4 pairs of artificial volume data two different types of optimizers were applied the Gradient Descent and the stochastic technique Robbins Monro. The parameters "#" and "A" of the decay function were set at 0.602 and 20 respectively, while for the "a" parameter of the decay function 3 different values were applied 10 100 and 100. The
selected interpolator was the linear one, for the first three levels and a 3-rd order B-spline for the last one. For each of the four volumetric pairs, two different cost functions were applied, the (Mutual Information (MI) and the Normalized Mutual Information (NMI)). In all cases. Thus, for each of the four pair of Images 24 registration parameter sets were evaluated.

**Evaluation**

Evaluation was performed based on Dice Similarity Coefficient (DSC), as well as mean value and percentage of negative values of the Jacobian matrix of the Transform. DSC, defined as

\[
dsc(X, Y) = \frac{2|X \cap Y|}{|X| + |Y|}
\]

**Fig. 3**

**References:** - /

where X,Y corresponds to the segmented volume of the original and registered image data respectively.

The Jacobian Matrix which defined as:
where $T$ is the Transform and $x=(x_1,x_2,x_3)$ is the transformed voxel location. The Jacobian Matrix calculated for every voxel, and afterwards the percentage of negative values and the mean values of the determinants of the Jacobian matrixes were calculated.
Fig. 1: Block Diagram of the Proposed Evaluation Methodology
Fig. 2: Multiresolution registration approach

\[ DSC(X, Y) = \frac{2|X \cap Y|}{|X| + |Y|} \]

Fig. 3
$$J(T \circ x) = \begin{bmatrix}
\frac{\partial T_{x_1}(x)}{\partial x_1} & \frac{\partial T_{x_1}(x)}{\partial x_2} & \frac{\partial T_{x_1}(x)}{\partial x_3} \\
\frac{\partial T_{x_2}(x)}{\partial x_1} & \frac{\partial T_{x_2}(x)}{\partial x_2} & \frac{\partial T_{x_2}(x)}{\partial x_3} \\
\frac{\partial T_{x_3}(x)}{\partial x_1} & \frac{\partial T_{x_3}(x)}{\partial x_2} & \frac{\partial T_{x_3}(x)}{\partial x_3}
\end{bmatrix}$$
Results

Table 1 summarizes the overall performance in terms of DSC and mean value and the percentage of negative values of Jacobian Matrix, of the evaluated parameters sets. The highlighted row represents the highest performance achieved.

**Fig. 5**: Table 1. The result of the evaluation for the 24 parameter sets. The highlighted row represents the highest performance achieved.

*References:* - /
A multi-resolution registration approach, with affine transform for the first three levels and third order B-Spline for the last level provided optimal results. The selected cost function was mutual information, and the standard gradient decent was used as optimizer. The selected interpolator was first order B Spline (linear) for the first three levels and third order B-spline for the last one. The selected image sampler was the random coordinate, with 5000 spatial samples. For the above set of parameters the DSC was 92.21%, while Jacobian Matrix mean value was 0.9997 with 0% of negative values. In all cases the registration schemes with the Gradient Decent optimizer, provided better performance comparative with the corresponding schemes of the Robbin Monro.

Fig. 6 on page 11 shows three registration results, obtained from the parameter set with the optimal performance. Each row corresponds to a different patient. The first column represents a segmented slice from the original scan (figure 3a, 3d, 3g), the second column represents the corresponding slice obtained from the artificial warped data (figure 3b, 3e, 3h), and the third one the registered slices (figure 3c, 3f, 3j). The yellow arrows, shows the corresponding vessel tree segments that indicates the registration success.
Fig. 5: Table 1. The result of the evaluation for the 24 parameter sets. The highlighted row represents the highest performance achieved.
Fig. 6: Registration results, obtained from the parameter set with the optimal performance. Each row corresponds to a different patient. The first column represents a segmented slice from the original scan (figure 6a, 6d, 6g), the second column represents the corresponding slice obtained from the artificial warped data (figure 6b, 6e, 6h), and the third one the registered slices (figure 6c, 6f, 6j). The yellow arrows show the corresponding vessel tree segments that indicates the registration success.
Conclusions

In this preliminary study, the performance of multi-resolution registration schemes is evaluated on volumetric Lung CT scans affected by ILD. Algorithms performances were evaluated by means of DSC and Mean values and percentages of negative values of Jacobian Matrix.

Artificial Data were selected to be evaluated, to avoid differences in voxel values between the original and registered pair due to alterations of lung parenchyma introduced by ILD progression.

Multiresolution techniques demonstrated promising performance and can be exploited in the framework of tools aimed at reproducible ILD disease progression estimation and added value services for patient management.