An automatic system for segmentation, matching, anatomical labeling and measurement of airways from CT images

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Purpose

Assessing airway dimensions and attenuation from CT images is useful in the study of diseases affecting the airways such as Chronic Obstructive Pulmonary Disease (COPD). Measurements can be compared between patients and over time if specific airway segments can be identified and measures performed in corresponding segments. However, manually finding corresponding segments and performing such measurements is time consuming and difficult. The purpose of the developed and validated system is to enable such measurements using automatic segmentations of the airway interior and exterior wall surfaces in three dimensions, anatomical branch labeling of all segmental branches, and longitudinal matching of airway branches in repeated scans of the same subject.

Methods and Materials

Airway tree segmentation

The fully automatic segmentation process begins by detecting a seed point within the trachea as a black circular region within the top slice. From this seed point the airway centreline tree is then iteratively extended by searching for locally optimal paths that most resemble the airway centrelines based on a statistical model derived from a training set. An initial segmentation of the airway lumen is then grown in a tubular fashion around the centreline. The method is described in detail in Lo et al. (2009). See fig. 1 for an illustration of the process.

Airway wall segmentation

The interior and exterior wall surfaces are found using a graph built from the initial airway tree segmentation. The graph directs the search for the surfaces along flow lines inward and outward from the initial segmentation and is able to simultaneously optimize the position of both, taking image gradient, surface smoothness and separation into account. Flow lines do not intersect and so the found surfaces are guaranteed not to self intersect. This results in good segmentations even in the otherwise very difficult to segment bifurcation regions. The approach is described in detail in Petersen et al. (2011). See fig. 2 for an illustration.

Airway branch matching

Using deformable image registration, corresponding points within two or more images of the same subject are found. Mass-preserving image registration as described by Gorbunova et al. (2012) is especially well suited to lung CT images because the model allows intensity variation, which is common due to differences in inspiration level, under the assumption of preservation of lung mass. See fig. 3 for an illustration of a registration result. Once corresponding points are found the centrelines are transferred to a common coordinate system in which the airway branches are matched based on distance and angle. Branches not found in all available images of the same subject are removed to correct possible segmentation errors and ensure corresponding measurements. The matching process is described in Petersen, Gorbunova et al. (2011) and fig. 4 illustrates the process.

Airway branch labeling

The anatomical names of all branches down to and including the segmental level are assigned based on distances to a training set of expert labeled trees. Distances are measured in a geometric tree-space, a mathematical construction, incorporating both topology and centreline shape differences. The method is described in Feragen et al. (2012).

Images for this section:

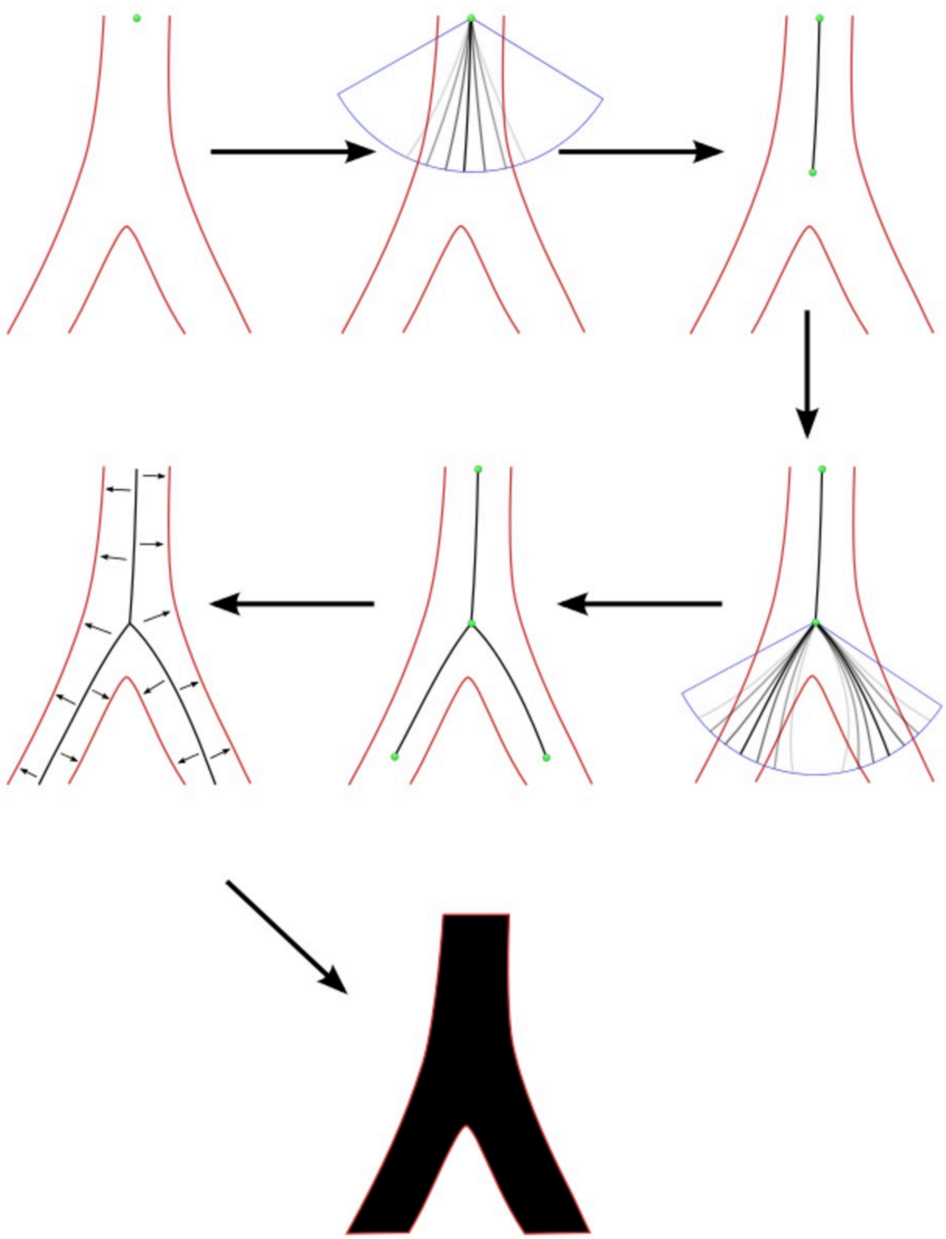

Fig. 1: The local optimal path approach of extracting the initial segmentation of the airway lumen.

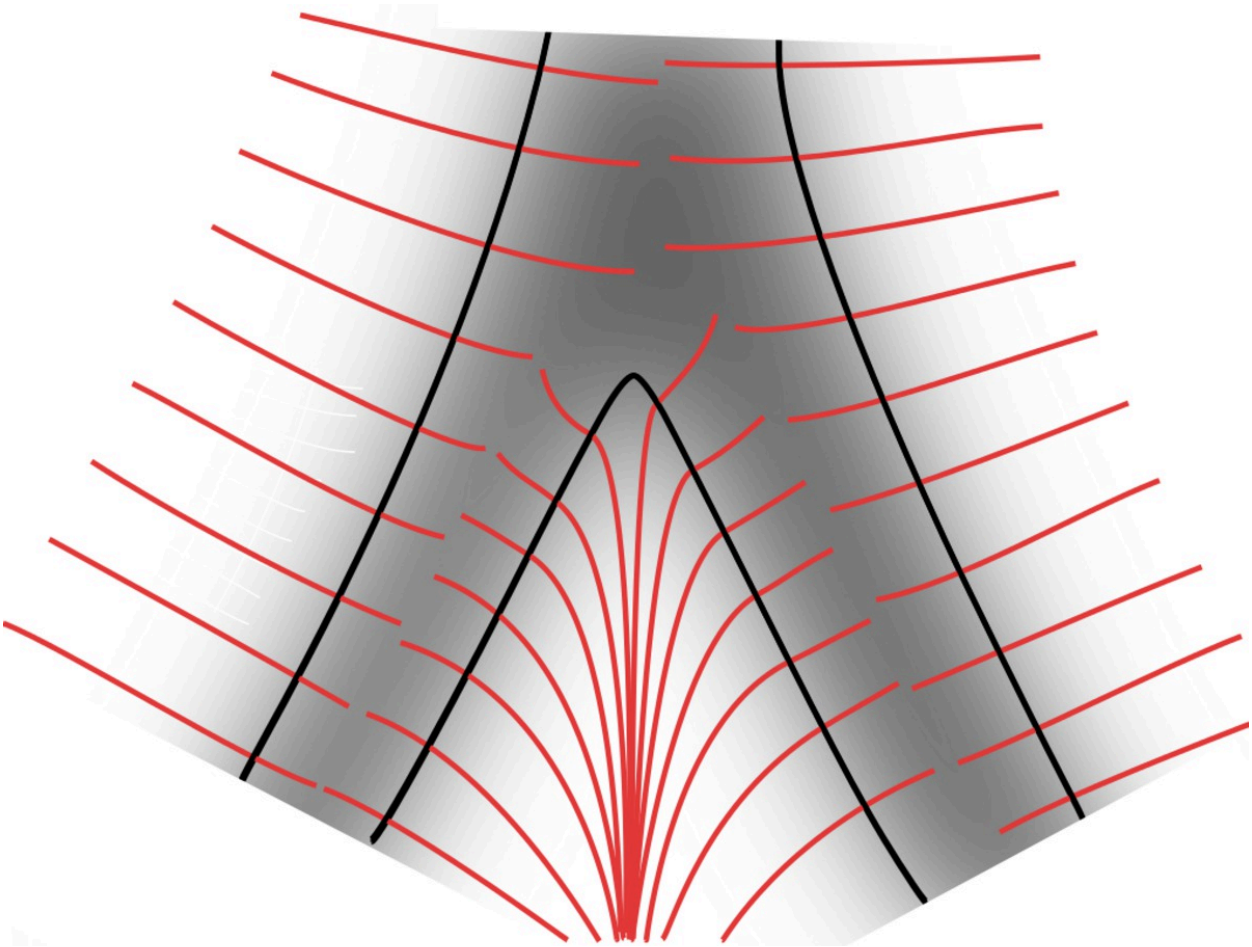

Fig. 2: The non-intersecting flow lines used in the graph based search for the interior and exterior airway wall. Notice how the lines represent ideal search directions.

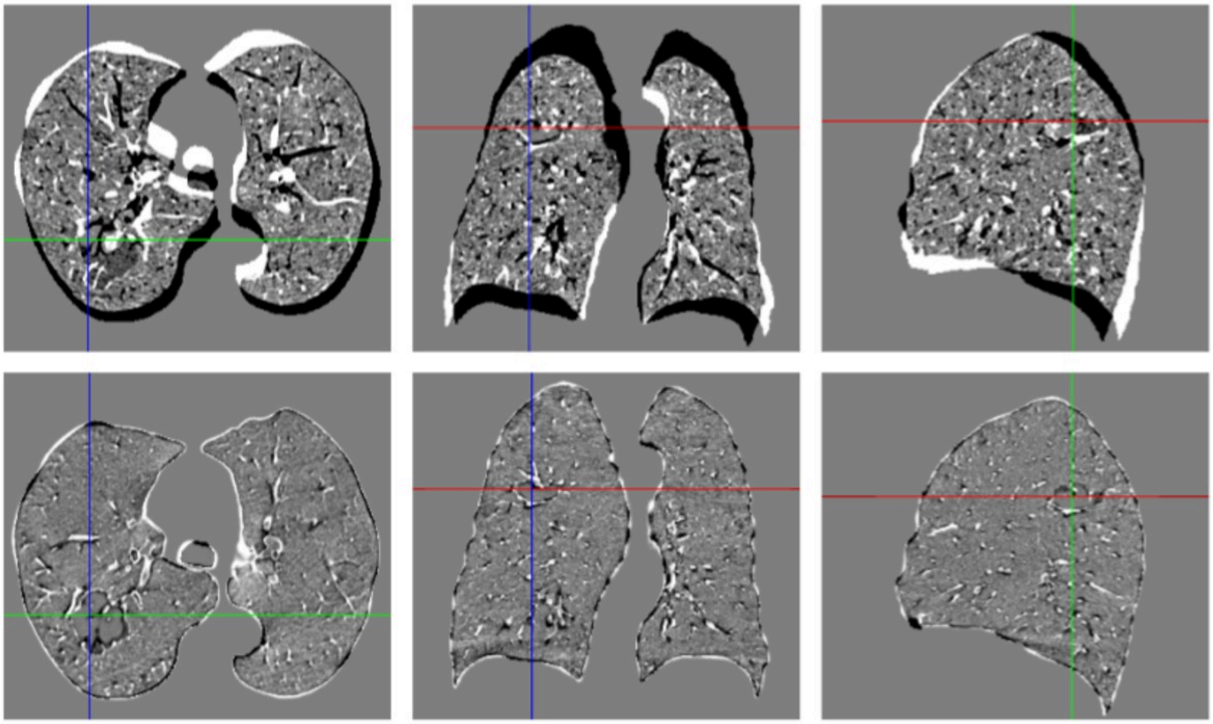

Fig. 3: Two scans of the same subject overlaid and subtracted. Axial, segmental and coronal views are shown with the non-registered on top and registered at the bottom. The registration process matches the images very well.

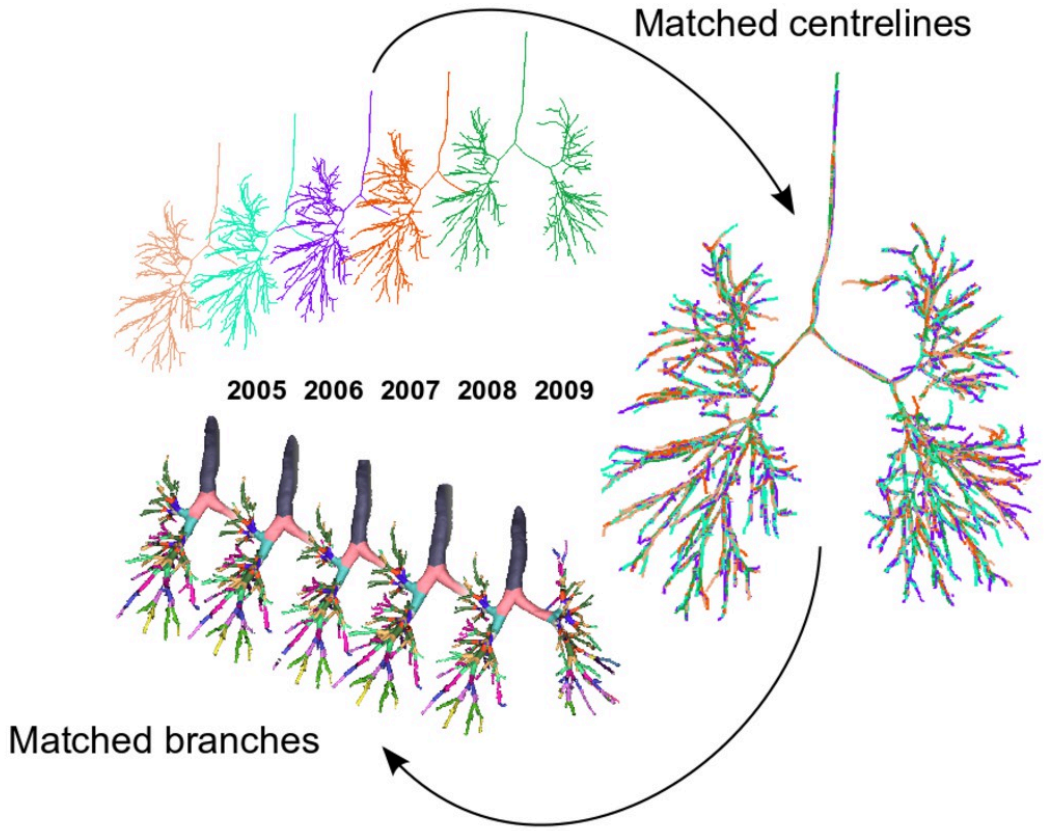

Fig. 4: The airway branch matching process. Yearly images of the same subjected are registered and the transformations are used to deform the airway centrelines to a common coordinate system in which matching is performed. The matched centrelines can then be used to investigate how airway abnormalities local to specific branches evolve over time.

Results

The segmentation method has been used on 9711 low dose CT images from the Danish Lung Cancer Screening Trial (DLCST). Manual inspection of thumbnail images revealed gross errors in a total of 44 images. 29 were missing branches at the lobar level and only 15 had obvious false positives. A thorough inspection of 10 randomly selected images, revealed the method extracted 174 branches on average and only 3.79% of the found centreline (excluding trachea and main bronchi) to be partially incorrect (Lo et al (2009)).

The extracted wall surfaces were compared to manual annotations in 319 reformatted slices extracted perpendicular to the centreline at random positions in 7 subjects. Results show an average Dice's coefficient of 89%. The COPD gene phantom was scanned with the DLCST protocol and our segmentation method estimated all interior and exterior diameters within 0.3 mm of their actual values. Fig. 5 shows a segmentation result. Lumen volume and wall area percentage measured in a random sub-population of DLCST (480 subjects at two time points) using the method was reproducible and significantly correlated with lung function (Petersen et al. (2011)).

Airway branch matching was initially investigated in Petersen, Gorbunova et al. on data from a randomly extracted sub-population of the DLCST consisting of 237 subjects scanned 5 times. Limiting measurements to branches matched in all scans of the same subject was seen to significantly increase their reproducibility, see fig. 6.

The anatomical branch labeling tool was validated (Feragen et al. (2012)) on a subset of 20 subjects, 5 of each category: asymptomatic, mild, moderate and severe COPD. The average inter-expert agreement of two trained observers in placing labels L1-L10 and R1-10 was found to be 71%, whereas the system reached 72.7%. Reproducibility of the experts in repeat scans of the same subject, assessed using image registration, was 72.6%, the system reached 76%. Accuracy did not become significantly lower in subjects with severe disease. Fig. 7 shows an airway
tree with automatically assigned labels and a developed tool in which the labels can be manually corrected if needed.

The framework has been used to investigate the effect of inspiration on the airway dimensions of the DLCST subjects with normal lung function. Results will be separately presented at ECR. Moreover work is ongoing to use the framework to investigate the association between airway distensibility and COPD.

Images for this section:

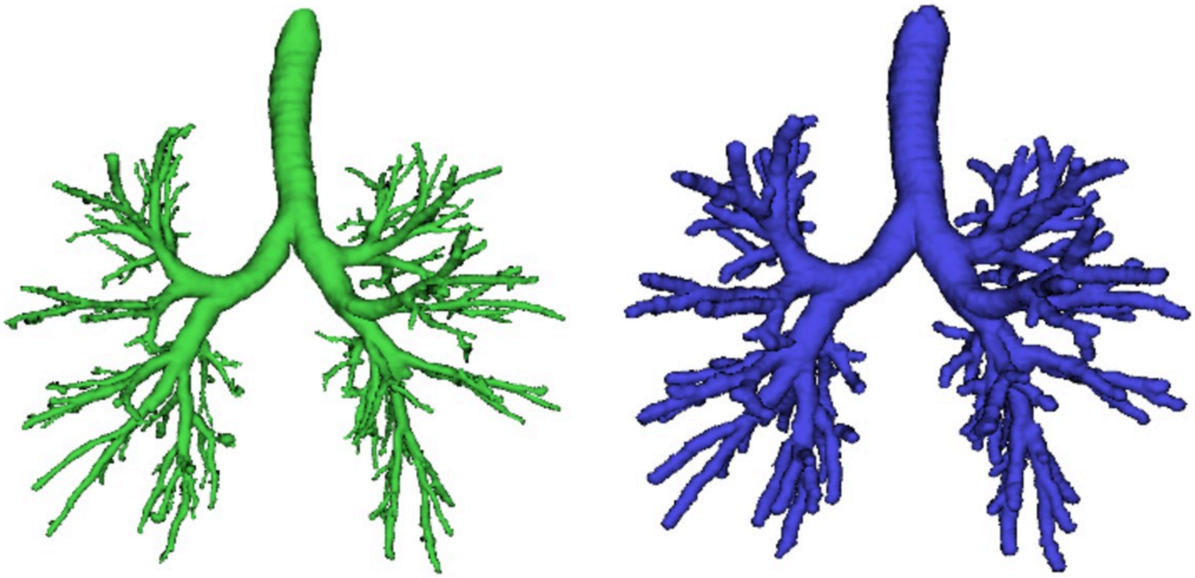

Fig. 5: A visualization of the results of the airway wall segmentation. The interior surface in green and the exterior surface in blue.

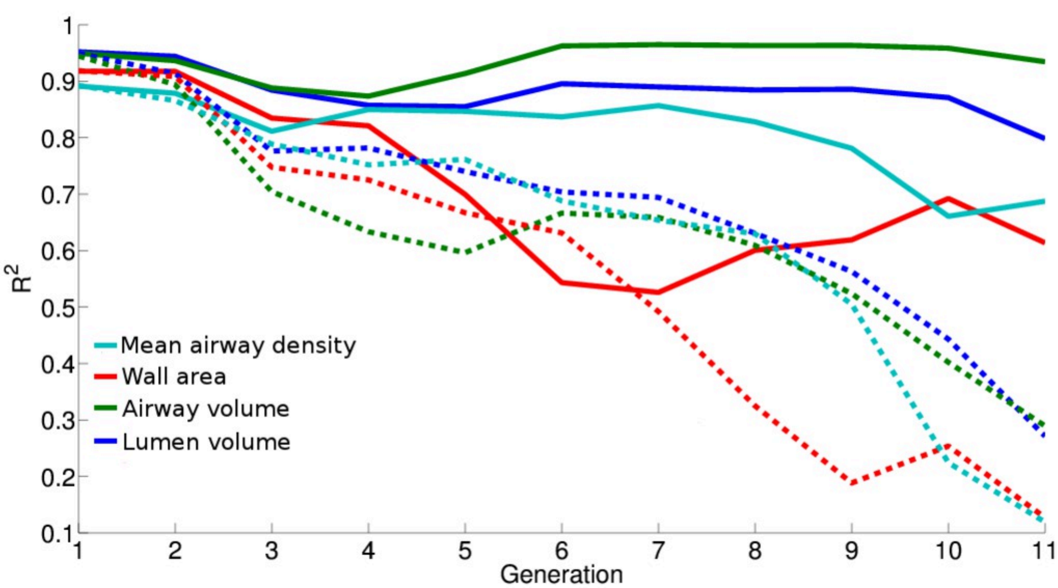

Fig. 6: The graph shows the repeat scan reproducibility of measured airway dimensions and attenuation values from branches in different airway generations (generation 1 correspond to the two main bronchi). The solid lines correspond to measurements limited

to branches matched in two scans and the dotted to all found airways. Matching is seen to increase reproducibility.

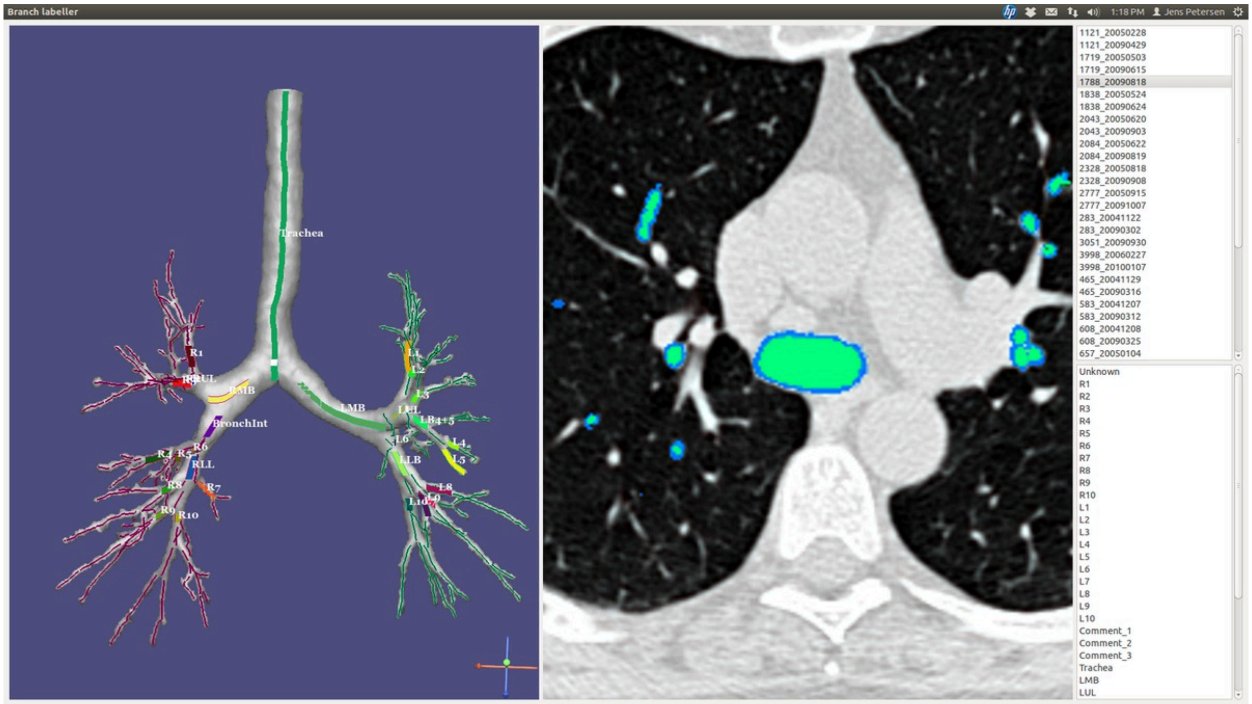

Fig. 7: The figure shows a visualization of automatically assigned airway branch labels in the branch labeller tool, which also allow manual correction and assignment of labels.

Conclusion

The presented system is able to segment the airway wall surfaces in CT images, identify segmental bronchi, and match segments in multiple scans of the same subject. This allows accurate, reproducible and completely automatic analysis of airways in clinical studies of COPD.

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