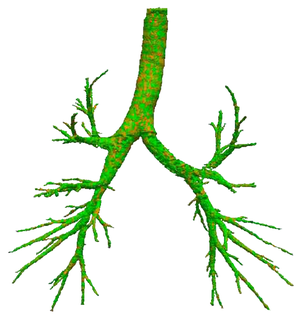
Fully Automated Extraction of Airways from CT Scans Based on Self-Adapting Region Growing



Oliver Weinheimer, Tobias Achenbach, and Christoph Düber

Department of Diagnostic and Interventional Radiology, Johannes Gutenberg University of Mainz, Germany

Introduction

A fast and reliable extraction of the airway tree is of fundamental importance for many clinical applications like a noninvasive 3D measurement and quantification of airway geometry, computer-assisted bronchoscopy or emphysema quantification. Low dose CT scans and ultra low dose scans are increasingly utilised in lung screening studies. Lowering the radiation exposure increases the amount of noise in the CT images, hence it increases the demands on fast and reliable airway extraction methods. So far, there have been no perfect extraction techniques, however events like EXACT09 are important for comparing and improving different airway extraction methods. We present a method for fully automated extraction of airways from volumetric computed tomography (CT) images based on a self-adapting region growing process. Former versions of our method have been used extensively in many clinical studies.

Fully Automated Extraction of Airways from CT

Depending on the quality of the data bronchial tree extraction can be a very challenging task - especially if it is a fully automated extraction. Our proposed method is based on the method first introduced in [1]. We improved the procedure over time while using it for many studies, see e.g. [2-4]. Firstly the histogram of a dataset is analysed. Secondly the trachea is searched and segmented. Thirdly the bronchial tree is segmented by a self-adapting region growing process

Step 1: Histogram Analysis

The fundamental importance of calibration for a CT system is indisputable. A CT system should be well calibrated, such that air is at -1000 HU, while water is at 0 HU. For this reason the first peak in the histogram of the first 10 upper slices of a dataset is determined and assigned to the variable T_{Air}.

- If $T_{\text{Air}} \neq T'_{\text{Air}}$ (see Fig. 1(a)(b)) →Apply Gaussian filter to each slice of the whole dataset.
- If $T_{\text{Air}} \neq$-1000 HU (see Fig. 1(c)(d)) →CT system is not well calibrated to air. The air calibration error will be dealt with in step 3.

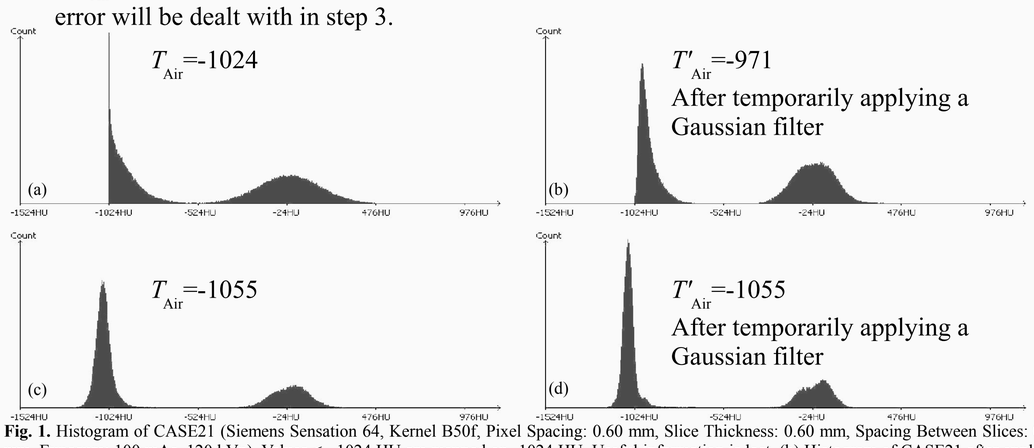


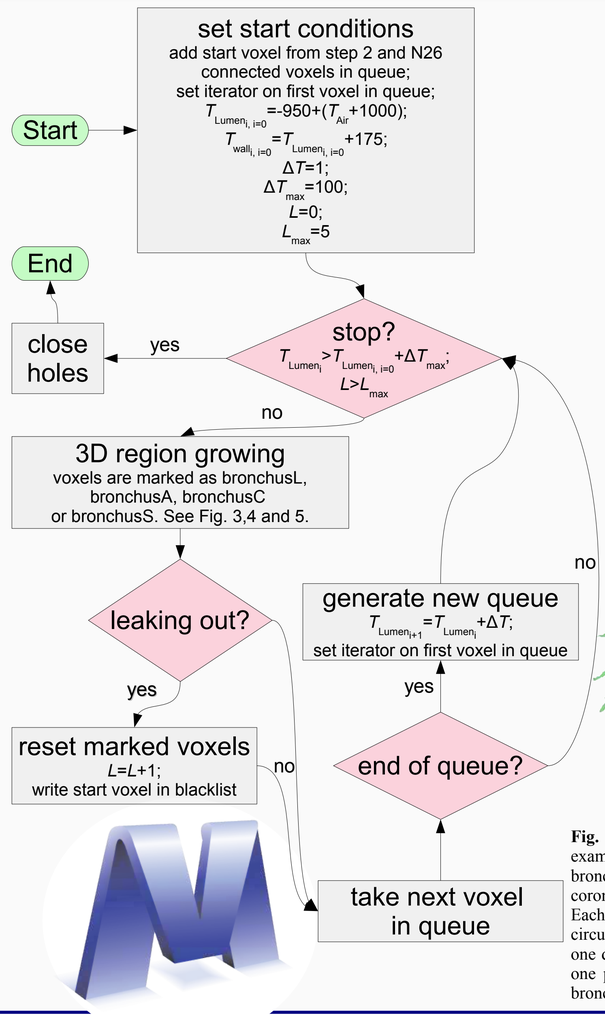
Fig. 1. Histogram of CASE21 (Siemens Sensation 64, Kernel B50f, Pixel Spacing: 0.60 mm, Slice Thickness: 0.60 mm, Spacing Between Slices: 0.60 mm, Exposure: 100 mAs, 120 kVp). Values < −1024 HU are mapped on -1024 HU. Useful information is lost. (b) Histogram of CASE21 after applying a Gaussian filter. T_{Air} is greater than -1000 HU because of the lost information described in (a). (c) Histogram of CASE24 (Toshiba Aquilion, Kernel FC12, Pixel Spacing: 0.65 mm, Slice Thickness: 1.00 mm, Spacing Between Slices: 0.8 mm, Exposure: 5 mAs, 120 kVp). (d) Histogram of CASE24 after applying a Gaussian filter. The Gaussian filter did not change the position of the first peak. This dataset is not well calibrated, because $T'_{\text{Air}} = T_{\text{Air}} =$ −1055. This indicates a calibration error of 55 HU.

Step 2: Searching for the Trachea

The trachea search is realised on the upper slices of a data set. A body detection is performed, so that the search area for the trachea can be limited to the body region. Then a circular region with voxel values < −500 HU (dark region) is searched on the axial slices inside the detected body. The 2D region must be greater than $5^2 \times \pi$ mm^2 and smaller than $15^2 \times \pi$ mm^2. The centre of gravity of the region is calculated and mapped on the succeeding slice. The mapped point should be part of a similar dark region, additionally the top of one lung is searched on this slice. If all conditions are fulfilled, a trachea landmark is found. If no Gaussian filter was applied to the dataset in step 1, the noise is quantified in the trachea region found and if necessary a 3×3 Gaussian mask is applied to the whole dataset. The trachea is then segmented with a 2D region growing with threshold value −500 HU, always mapping the centre of gravity of a marked region to the succeeding slice in basal direction as a new seed point. The procedure stops if the carina (main bifurcation of the trachea) is reached, see Fig. 2.

Fig. 2. Segmented trachea.

Step 3: Self-Adapting Region Growing



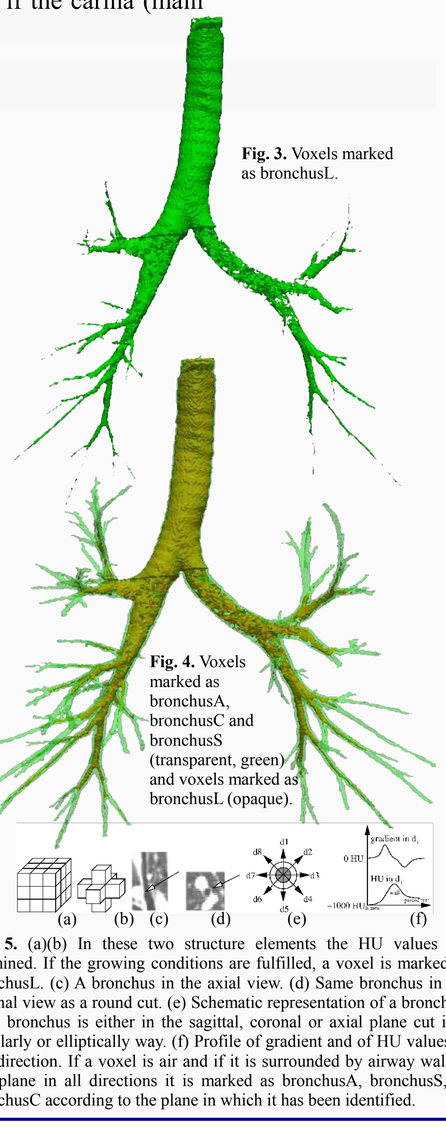


Fig. 3. Voxels marked as bronchusL.

Fig. 4. Voxels marked as bronchusA, bronchusC and bronchusS (transparent, green) and voxels marked as bronchusL (opaque).

Fig. 5. (a)(b) In these two structure elements the HU values are examined. If the growing conditions are fulfilled, a voxel is marked as bronchusL. (c) A bronchus in the axial view. (d) Same bronchus in the coronal view as a round cut. (e) Schematic representation of a bronchus. Each bronchus is either in the sagittal, coronal or axial plane cut in a circularly or elliptically way. (f) Profile of gradient and of HU values in one direction. If a voxel is air and if it is surrounded by airway wall in one plane in all directions it is marked as bronchusA, bronchusS, or bronchusC according to the plane in which it has been identified.

Results

The images used in this challenge were volumetric chest CT scans acquired at different sites using several different scanners, scanning protocols, and reconstruction parameters. The images were divided into two sets: a training set (CASE01-CASE20) and a testing set (CASE21-CASE40). We used the training set in order to slightly modify our existing method so that it was able to cope with the EXACT data. The datasets range from clinical dose to ultra low dose scans, from healthy volunteers to patients with severe lung disease, and from full inspiration to full expiration. Table 1 documents the results achieved with our method for the 20 cases in the testing set. An average number of 130.1 branches were detected in the datasets (mean value for all participating teams: 124.01). The mean value for the leakage volume was 559.0 mm^3 (mean value for all teams: 700.55 mm^3). The average runtime on a PC (Intel Xeon CPU, 2.83 GHz, 4GB RAM) per case of the testing set was 183 s, 39 s for Step 1 and 2 and144 s for Step 3. Fig. 6(a)(b) shows CASE22, where the greatest number of branches were determined. Fig. 6(c) shows CASE32, where the greatest leakage volume was measured.

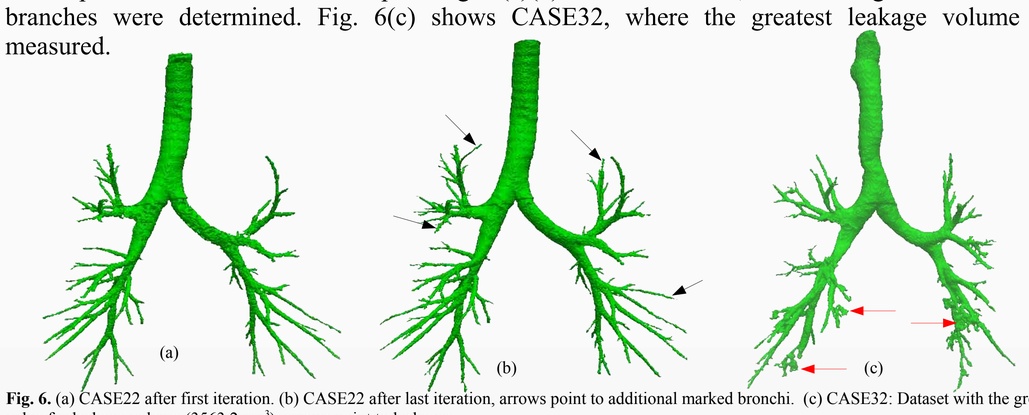


Fig. 6. (a) CASE22 after first iteration. (b) CASE22 after last iteration, arrows point to additional marked bronchi. (c) CASE32: Dataset with the greatest value for leakage volume (3563.2mm^3), arrows point to leakages.

	Branch count	Branch detected (%)	Tree length (cm)	Tree length detected (%)	Leakage count	Leakage volume (mm^3)	False positive rate (%)
CASE21	103	51.8	54.7	49.5	3	651.4	6.93
CASE22	252	65.1	181.3	54.9	2	8.9	0.04
CASE23	154	54.2	100.6	38.7	0	0.0	0.00
CASE24	101	54.3	76.0	46.7	0	0.0	0.00
CASE25	134	57.3	100.7	40.0	0	0.0	0.00
CASE26	39	48.8	28.8	43.8	0	0.0	0.00
CASE27	34	33.7	25.0	30.8	0	0.0	0.00
CASE28	98	79.7	71.6	65.3	7	214.3	1.69
CASE29	111	60.3	69.8	50.6	5	131.3	1.04
CASE30	144	73.8	108.8	71.2	12	2226.0	12.37
CASE31	173	80.8	134.2	76.5	21	1956.2	7.38
CASE32	155	66.5	130.6	60.0	20	3563.2	10.79
CASE33	119	70.8	87.2	59.3	1	15.3	0.15
CASE34	251	54.8	158.6	44.3	0	0.0	0.00
CASE35	104	30.2	64.9	21.0	0	0.0	0.00
CASE36	129	35.4	135.1	32.8	0	0.0	0.00
CASE37	52	28.1	44.8	25.2	0	0.0	0.00
CASE38	35	35.7	27.7	41.7	0	0.0	0.00
CASE39	176	33.8	129.3	31.6	12	461.3	3.51
CASE40	238	61.2	187.0	48.3	29	1952.7	5.46
Mean	130.1	53.8	95.8	46.6	5.6	559.0	2.47
Std. dev.	66.1	16.6	49.3	14.9	8.7	1019.3	3.95
Min	34	28.1	25.0	21.0	0	0.0	0.00
1st quartile	98	35.4	54.7	32.8	0	0.0	0.00
Median	124	54.6	93.9	45.5	1	4.5	0.02
3rd quartile	176	70.8	135.1	60.0	12	1952.7	6.93
Max	252	80.8	187.0	76.5	29	3563.2	12.37

Table 1. Evaluation measures for the 20 cases in the test set.

Conclusion

We presented a method for fully automated extraction of airways from CT Scans. Our proposed method was able to extract the bronchial tree fully automatic in all 40 datasets. Our implemented leakage detection is just based on the number of added voxels by a single region growing process - this simple rule should be improved, shape features can be used for this purpose. This should allow the segmentation of more peripheral bronchi. The rules for the detection of smaller airways in step 3 should be reworked and additionally more than the 3 main cutting planes (axial, sagittal, coronal) should be used for the decision-making process. Furthermore, 2D airway detection should be applied to a dataset and the results connected to the 3D segmentation. This can help to detect airway stenosis. Our method worked well on the challenging datasets of EXACT09, nevertheless we have gathered valuable information for our future work. Generating a common database covering a wide range of possible CT scans is an important step for improving and comparing different airway extraction methods.

Literature

[1] Weinheimer, O., Achenbach, T., Buschsieweke, C., Heußel, C.P., Uthmann, T., Kauczor, H.U.: Quantification and Characterization of Pulmonary Emphysema in Multislice-CT: A Fully Automated Approach. In Petra Perner, Rüdiger W. Brause and Hermann-Georg Holzhütter, eds.: Medical Data Analysis, 4th International Symposium, ISMDA 2003, Berlin, Germany, October 9-10, 2003, Proceedings. Volume 2868 of Lecture Notes in Computer Science. Springer (2003)

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Further Information

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