ELSEVIER

www.ics-elsevier.com

A method for automated nomenclature of bronchial branches extracted from CT images

Kensaku Mori[a,*], Shinya Ema[a], Takayuki Kitasaka[a],
Yoshito Mekada[b], Ichiro Ide[a], Hiroshi Murase[a], Yasuhito Suenaga[a],
Hirotsugu Takabatake[c], Masaki Mori[d], Hiroshi Natori[e]

[a]*Graduate School of Information Science, Nagoya University, Japan*
[b]*School of Life System Science and Technology, Chukyo University, Japan*
[c]*Minami-Sanjyo Hospital, Japan*
[d]*Sapporo-Kosei Hospital, Japan*
[e]*School of Medicine, Sapporo Medical University, Japan*

Abstract. This paper describes a method for automated nomenclature of bronchial branches extracted from CT images. When a medical doctor diagnoses chest CT images, lesions' locations are identified by dominant bronchial branches' names. Also, in the case of real or virtual bronchoscopy, a physician performs bronchoscopy with understanding current locations by branches' names. In the previous method, several branching-pattern models were constructed for automated labeling of bronchial branches extracted from CT images. These models were prepared for each part of the bronchus. An appropriate model was selected by evaluating the average differences of running directions of bronchial branches between the models and the extracted tree structure part by part. However, the previous method selected the wrong model and assigned incorrect names. To solve such miss-labeling, the proposed method removes some models from the candidate models for labeling by checking branching pattern in each branching point during labeling process. Also, the proposed method removes models by checking directions of segmental bronchi and selects a model from remaining models in the labeling process of the right upper lobe. In the experiments using 26 cases of chest CT images, the proposed method was able to correctly assign 90% of segmental bronchial branches. © 2005 CARS & Elsevier B.V. All rights reserved.

Keywords: Anatomical labeling; Bronchus; Bronchial branch model; Chest

---

* Corresponding author.
   E-mail address: kensaku@is.nagoya-u.ac.jp (K. Mori).

1. Introduction

Recent progress of CT scanners has enabled us to take quite a lot of precise images of a human body in very short time. CAD systems that can effectively use the information contained in such CT images are strongly expected to be developed for accurate diagnosis or examination. In the case of the diagnosis of the lung, the bronchus is a quite important organ. The lung areas can be divided into segmental lobes based on dominating bronchial branches. The bronchial branch names are systematically assigned to each bronchial branch. When a medical doctor diagnoses chest CT images, lesions' locations are identified by dominant bronchial branches' names. Also, in the case of real or virtual bronchoscopy, a physician performs bronchoscopy with understanding current locations by branches' names. Sometimes, target positions for biopsy or observation are described by anatomical names of branches. Very few researches were performed in the area of automated nomenclature of bronchial branches that is extracted CT images [1–4]. In the reference [1], one branching model was prepared before the labeling process. The model has information of running directions, parent branch names, and child branch names of bronchial branches. We obtained graph representation of the tree structure of the bronchial region extracted from a 3-D CT image by using a thinning method. Actual nomenclature (or labeling process) was performed by selecting the most appropriate branch information from the model for each branch of the tree structure. This process was executed from the central to the peripheral parts. The problem of this method was it is impossible to deal with variations of branching patterns. In the reference [4], multiple models for four parts (right upper, right middle and lower, left upper, and right lower parts) were introduced to treat these variations. However, selection of an appropriate model was done by evaluating the average differences of running directions of bronchial branches between the models and the extracted tree structure part by part. Thus, the previous method selected the wrong model and assigned incorrect names. To solve such miss-labeling, the proposed method removes some models from the candidate models for labeling by checking branching pattern in each branching point. In the right upper lobe, the proposed method removes models by checking directions of segmental bronchi, and selects a model from remaining models.

In Section 2, we show brief explanation of the procedure for automated nomenclature of bronchial branches extracted from CT images. Automated nomenclature method for the right upper lobe and the remaining parts are presented. Section 3 shows some examples of experimental results and brief discussion.

2. Methods

2.1. Bronchial branch model

The bronchial model is a graph representation that shows branching patterns of bronchial branches in each part (RU: right upper lobe, RL: right middle and lower lobes, LU: left upper lobe, LL: left lower lobe). The p-th model M_q^p for the part q has the end points e_i of branches belonging to M_q^p and their properties v_i. Each branch in M_q^p has three kinds of attributions: (a) anatomical names, (b) parent branch name, and (c) running direction. These models for each part (RU ($q=0$), RL ($q=1$), LU ($q=2$), LL

(q=3)) were prepared by using hand-labeled bronchial branches extracted from multiple cases of CT images.

2.2. Overview

First, we extract tree structure of bronchi regions from 3-D chest CT images by using tree-structure tracing algorithms shown in the reference [5]. In the labeling process of trachea and main bronchi, we use the method presented in the reference [1]. For the right upper lobe (RU), we assign anatomical labels by using the method shown in Section 2.3. For other parts (RL, LU, LL), labeling is performed by the method shown in Section 2.4.

2.3. Labeling for RU part

2.3.1. Temporal labeling

Let **B** be a child branch of the upper lobe bronchus (a child of right main bronchus). We sequentially execute labeling process from **B** to peripheral branches by using models M_0^i and save them as temporally labeling results. Anatomical name assignment is performed by selecting a branch, whose running direction is close to a target branch, from a model.

2.3.2. Model selection

By using temporal labeling results, we remove inappropriate models from candidate models for the RU part. First, we calculate three vectors that start from B and direct to the ends of the branches labeled as B_1, B_2, and B_3 by the model M_0^i. We denote these vectors as U_1, U_2, and U_3. Also, we calculate three vectors V_1, V_2, and V_3 on the model M_0^i in the same way. If one of inner products $V_1 \cdot U_1$, $V_2 \cdot U_2$, or $V_3 \cdot U_3$ is smaller than a given threshold value, the model M_0^i is removed from the model candidate for the RU part. This process is iterated for all models prepared for the RU part.

2.3.3. Final labeling

We execute the labeling process by using the remaining models. For each model, we deform the model so that the model fits to the input tree structure and calculate an average angle of deformation. The final labeling was performed by the model whose average deformation angle is the smallest one among the models. Anatomical names of the deformed model are assigned to branches of the input tree structure.

2.4. Labeling for remaining parts

For each child branch of main bronchi (except for the upper lobe bronchus), we perform the following steps. Illustrated explanation of the model selection is shown in Fig. 1.

(1) We assign anatomical name to a child branch of the main bronchus. We store the child branch and candidate models (i.e. left upper lobe bronchus and all models of LU in the case of LU) into a stack.

(2) If the stack is empty, the process is terminated. If not, we retrieve a branch and a set of candidate models. The retrieved branch is denoted as the target branch **O**.

(3) If **O** does not have a child branch, return to step (2). If it has, we search branches E_p whose anatomical names are same as **O**'s name in each candidate model. For E_p of

Fig. 1. Illustrative explanation of model selection procedure for RL (Right Middle and Lower Lobe) part. For each branching point, a set of model candidates is defined.

each candidate model, rotate O and its child branches so that the running direction of E_p becomes equal to that of O. For all of possible combinations of one-to-one correspondence between child branches of O and E_p, we calculate the sum of inner products of running directions of corresponding pairs. We consider the combination showing the highest sum of inner products as the most appropriate combination in the model. We calculate this combination for all of candidate models.

(4) We select the candidate model, which shows the highest sum among the candidate models, as the best model and assign anatomical names of the child branches O by using the selected model (names are copied from corresponding branches in the model to the child branches of O).

(5) We reconfigure a set of candidate models. If the number of child branches of E_p and their anatomical names in a candidate model differs from those of the best model, the candidate model is removed from the set.

(6) Store the child branches of O and a new set of candidate models into the stack and return to step (2).

3. Experimental results and discussion

We applied the proposed method to bronchial branches extracted from 25 cases of chest CT images. Bronchial branch models were generated from 24 cases which excludes the case of labeling target (Leave-one-out method). For each case, a medical doctor assigned

Table 1
Results of automated nomenclature for segmental branches extracted from CT images by the previous and proposed methods (TR: Trachea; LM: Left Main Bronchus; RM: Right Main Bronchus; RU: Right Upper Lobe; RL: Right Middle and Lower Lobe; LL: Left Lower Lobe)

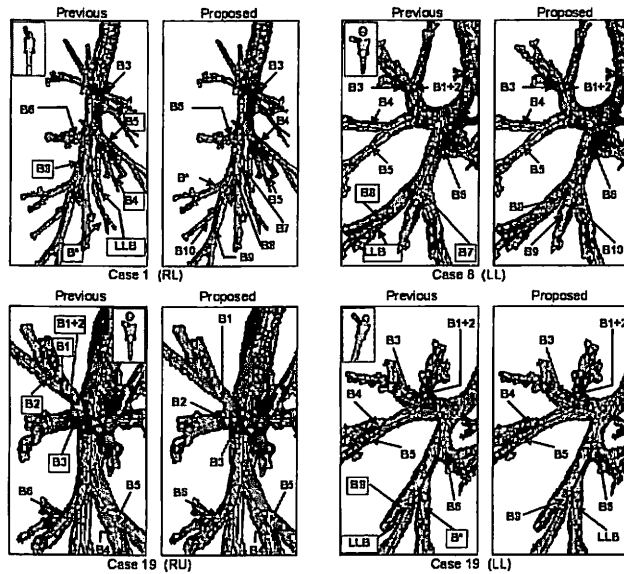|	Number of branches	Number of branches to which correct anatomical names are assigned	
		Previous	Proposed
TR LM RM	75	75 (100%)	
RU	124	106 (85.5%)	110 (88.7%)
RL	322	268 (83.2%)	291 (90.4%)
LU	183	159 (86.9%)	165 (92.0%)
LL	184	146 (79.3%)	158 (85.9%)
Total	888	754 (84.9%)	799 (90.0%)

Fig. 2. Examples of labeling results by the previous and proposed methods. Anatomical names in boxes show incorrect labeling results (RU: Right Upper Lobe. RL: Right Middle and Lower Lobe. LL: Left Lower Lobe.).

anatomical names manually. The numbers of models were: 6 models for RU, 8 for RL, 5 for LU, and 6 for LL. Labeling accuracy of the proposed method was 100% for trachea and main bronchi, 88.7% for RU, 90.4% for RL, 90.2% for LU, and 85.9% for LL, while 100% for trachea and main bronchi, 85.5% for RU, 83.2% for RL, 86.9% for LU, and 79.3% for LL by the previous method (Table 1). Total labeling accuracy was 90.0% for the proposed method and 84.9% for the previous. These labeling results were validated by medical doctors. Examples of labeling results are shown in Fig. 2. In this figure, anatomical names in boxes show incorrect labeling results. It is clear that the proposed method much improved labeling accuracy in comparison with the previous method. This is because the proposed method selected appropriate models as branching level goes further. Also, the special procedure for RU part contributed to increase labeling accuracy. Incorrect labeling was prevented by checking dominant regions of B1, B2, and B3 branches.
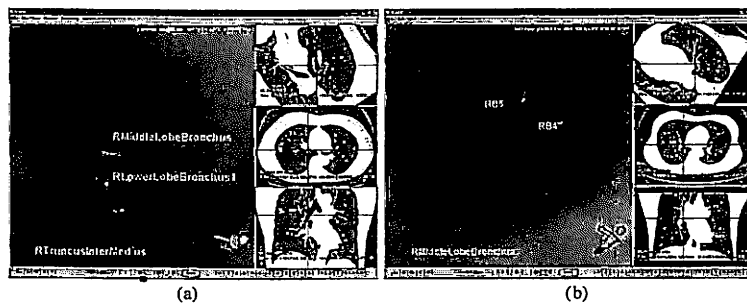

Fig. 3. Automated anatomical name display on virtual bronchoscopic images. (a) Case 1; (b) Case 11.

Examples of automated anatomical name display on virtual bronchoscopic images are shown in Fig. 3. These names are displayed by using labeling results. Anatomical name display helps to understand observation locations.

4. Conclusion

This paper presented a method for automated nomenclature of bronchial branches. Appropriate models are used at each branching point by introducing candidate model disselection scheme. For the upper lobe bronchus, a special procedure is prepared for checking dominant regions of B1, B2, and B3. The experimental results showed that the proposed method could correctly assign anatomical names to 90% of bronchial branches extracted from CT images. Future work includes (1) application to large number of cases, (2) improvement of model disselection or model selection, and (3) use of dominant region information.

Acknowledgement

References

[1] K. Mori, et al., Automated anatomical labeling of the bronchial branch and its application to the virtual bronchoscopy system, IEEE Transactions on Medical Imaging 19 (2000).

[2] H. Kitaoka, et al., Automated nomenclature labeling of the bronchial tree in 3D-CT lung images, in: T. Dohi, R. Kikinis (Eds.), MICCAI2002, LNCS, vol. 2489, 2002, pp. 1–11.

[3] J. Tschirren, et al., Segmentation, skeltonization, and branchpoint matching—a fully automated quantitative evaluation of human intrathoracic airway trees, in: T. Dohi, R. Kikinis (Eds.), MICCAI2002, LNCS, vol. 2489, 2002, pp. 12–19.

[4] S. Ema et al., An improved method for automated anatomical labeling of bronchial branches extracted from 3-D CT images.

[5] T. Kitasaka, et al., A method for extraction of bronchus regions from 3D Chest X-ray CT images by analyzing structural features of the bronchus, Forma 17 (2002) 321–338.