Automated Labeling of Bronchial Branches in Virtual Bronchoscopy System

Kensaku MORI¹, Jun-ichi HASEGAWA², Yasuhito SUENAGA¹,
Jun-ichiro TORIWAKI³, Hirofumi ANNO⁴, and Kazuhiro KATADA⁴

¹ Dept. of Computational Science and Engineering, Graduate School of Engineering,
Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi, 464-8603 JAPAN

{mori,suenaga}@nuie.nagoya-u.ac.jp,

WWW home page: <http://www.toriwaki.nuie.nagoya-u.ac.jp/~mori>

² School of Computer and Cognitive Sciences, Chukyo University,
101, Tokodachi, Kaizu-cho, Toyota, Aichi, 470-0348 JAPAN

hasegawa@scs.chukyo-u.ac.jp

³ Dept. of Information Engineering, Graduate School of Engineering,
Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi, 464-8603 JAPAN

toriwaki@nuie.nagoya-u.ac.jp

⁴ School of Health Sciences, Fujita Health University,
Dengkugakubo, Kutsukake-cho, Toyoake, Aichi, 470-1192 JAPAN

{hanno, kkatada}@fujita-hu.ac.jp

Abstract. This paper proposes a method for automated labeling of bronchial branches in virtual bronchoscopy system. Anatomical names of bronchial branches are assigned basing upon a set of rules. If it is possible to assign the anatomical names to bronchial branches extracted from CT images by the computer and is possible to display the name of the currently observed branch on a virtual bronchoscopy image, it will help us to understand the current observing position. The proposed method constructs the knowledge base of anatomical names of bronchial branches. Tree structure of bronchus region is extracted from CT image. Labeling is performed by comparing tree structure information of the extracted bronchus with information of the branches described in the knowledge base. We implemented the proposed method with the virtual bronchoscopy system and obtained satisfactorily result.

1 Introduction

Rapid progress of three dimensional imaging equipment enables us to acquire very precise 3-D images of human body. However the doctors' load of diagnosing them is increasing. Therefore useful observation methods for those 3-D image are strongly expected. Virtualized endoscope system (virtual endoscopy system) has been developed as one of new observation tools of 3-D images. This system enables us to fly through inside and outside the human body in real time. If it is possible to display the anatomical name of the organ in a view of virtualized endoscope system corresponding to changing viewpoints and view directions, this will help us to know the current observation point.

Many researchers have reported a various kind of automated extraction methods of the organ from 3-D medical images. However there was no report about automated assignment of anatomical names to the organs extracted from a 3-D image. While some researchers including authors have reported about virtual endoscopy system, no paper has been published for automated display of the anatomical name of the organ in virtual endoscopy system [1–7]. Hoehne and colleagues have constructed the atlas of human body on computer. Anatomical names which are labeled manually are displayed on the rendered image of organ as the atlas [8]. Our method automatically assigns the anatomical name of the bronchus by using the knowledge base of the anatomical name of the bronchus and display the assigned result on the virtual bronchoscopy image corresponding to the viewpoint and view direction for helping the user to understand the current observation point.

This paper describes about a method for automated assignment of anatomical names of bronchial branches which were extracted from 3-D chest X-ray CT images and its application to virtual bronchoscopy system [9] for displaying branch names in the system. In section 2, the outline of the knowledge base of anatomical names of bronchial branches is briefly described. Section 3 shows the whole procedure of automated assignment and the method for displaying the branch name in the virtual bronchoscopy system. Experimental results are shown in Section 4 and brief discussion is added to the results.

2 Knowledge Base of Anatomical Names of Bronchial Branch

Bronchus is the organ which has the tree structure. The anatomical name of each branch is assigned basing upon a set of rules. We implement this assignment rule of anatomical name as knowledge base. Assignment of branch names is performed by comparing this knowledge base and the branching structure of bronchus which was extracted from a given CT image.

The algorithm of this name assignment accompanies the knowledge base of anatomical name of bronchial branch described by the frame representation which is one of the well-known methods for knowledge representation (Fig.1). Each frame keeps the knowledge of each branch consisting of the information of tag name, anatomical name, parent branch name, position and direction of branch, and weighted value for each evaluation item.

3 Processing Procedure

3.1 Automated Labeling of The Anatomical Name of Bronchial Branches

Fig.2 shows the processing procedure of automated labeling of bronchial branches. In the procedure, the bronchus region is extracted from 3-D CT images. Tree structure of bronchus is obtained from the extracted region. Automated labeling is performed, being based on the extracted tree structure of bronchus.

Fig. 1. An example of the knowledge base represented by frame description method. (a) overview of knowledge base, and (b) knowledge of one branch of the bronchus

Fig. 2. Automated labeling procedure (automated assignment of anatomical name for bronchial branches)

1) Extraction of Branching Structure of Bronchus (Fig. 3) The bronchus region is extracted from 3-D chest X-ray CT image automatically by employing the method shown in [9]. This method segments the bronchus region by thresholding for CT numbers. The threshold value is automatically adjusted. The medial axis of the bronchus is calculated by using the thinning method [10]. Branching structure of bronchus is extracted from the thinned image [11]. The graph representation is generated also from the thinned result. In the graph, trachea is the root and each branches and branching points of bronchus are represented by arcs and nodes of the graph, respectively. Each arc (branch) has the following information: connecting branching point, direction of the arc, and the pointers to the parent arc and the child arc.

2) Labeling of Anatomical Name for Each Branch This procedure assigns the anatomical name to the bronchial branch by comparing the knowledge base with the structure information extracted in 1). The assignment procedure starts from the trachea and is performed sequentially from the center to the peripheral by the depth first search. The method selects the most appropriate name of a

bronchial branch, which is described in the knowledge base, for each branch of the bronchial tree. Selection is performed by finding the branches of the knowledge base which has the highest evaluation value. Evaluation value is calculated from the information (such as running direction, parent branch) of each branch which is extracted from a CT image and the information described in the knowledge base. The following shows the detail of the procedure.

step1) The tree structure information of the extracted bronchus and the knowledge base are inputted.

step2) One branch B_i (B_i means the branch i of the bronchus extracted from a given CT image. $B_i \in \{\text{all branches of the bronchus extracted from CT image}\}$) is selected from tree structure. This selection is performed sequentially for all branches of the bronchus extracted from CT image by the depth search from trachea.

step3) Evaluation values E_{ij} for B_i and K_j are calculated (K_j means the branch j described in the j -th item of the knowledge base. $K_j \in \{\text{all branches described in the knowledge base}\}$) for all j . The evaluation value E_{ij} is calculated by

$$E_{ij} = w_d \frac{\mathbf{d}_{B_i} \bullet \mathbf{d}_{K_j}}{|\mathbf{d}_{B_i}| |\mathbf{d}_{K_j}|} + w_p V \quad (1)$$

where $\mathbf{d}_{B_i}$ represents the running direction of the branch B_i , $\mathbf{d}_{K_j}$ the running direction of the branch K_j . w_d and w_p are weighted values. V takes V_p if the anatomical name of the parent branch of B_i is equal to the name of the parent branch of K_j , or 0 if the name is not equal.

step4) The branch $K_{j_{max}}$, which has the highest evaluation value for B_i and its evaluation value is greater than a given threshold value, is selected from a set of branches described in the knowledge base. Then we assign the anatomical name of $K_{j_{max}}$ to the branch B_i . If we could not find the branch $K_{j_{max}}$ which satisfies the above stating condition, assignment is not performed for B_i . If $K_{j_{max}}$ was already assigned to another branch B_l , we compare two evaluation values $E_{ij_{max}}$ (evaluation value for B_i and $K_{j_{max}}$) and $E_{lj_{max}}$ (evaluation value for B_l and $K_{j_{max}}$). If $E_{ij_{max}} > E_{lj_{max}}$, the branch name of $K_{j_{max}}$ is assigned to B_i and assignment to B_l and its child branches are canceled. Otherwise the assignment is not performed.

Fig. 3. Extraction of the tree structure of bronchus from a 3-D CT image

Fig. 4. Processing procedure for automated display of anatomical names of bronchial branches

Fig. 5. Selection of the branch corresponding to the current view point

step5) If all branches have been processed, go to step6). Otherwise, go to step2).

step6) If new assignment is performed in the iteration of step2)-step6), go to step2) and start from trachea again. Otherwise, labeling is terminated.

3.2 Display of The Branch Name in Virtual Bronchoscopy System

Anatomical names of bronchial branches are displayed in the virtual bronchoscopy system (Fig.4) which we have developed [4,6]. In the virtual bronchoscopy system, bronchus region is extracted from a 3-D chest X-ray CT image. The shape of bronchus is represented by triangle patches. Marching Cubes method [12] was employed here for patch generation and the triangle patches are rendered by gouraud shading, perspective projection and spot light model. The user can specify the viewpoint and the view direction by mouse interactively and the corresponding image is rendered in real time.

The branch corresponding to the current viewpoint is found from the branching structure of the bronchus extracted in 3.1 1). The current branch is determined by calculating the closest branch from the current viewpoint. The current observation direction (“from center to peripheral” or “from peripheral to center”) is also found automatically by the angle of the current view direction and the direction of the closest branch (Fig.5). When the observation direction is “from center to peripheral”, we select two types of branches for displaying anatomical names, the branch which corresponds to the current viewpoint and the branches which are one level ahead (Fig.6). When the view direction is “from peripheral to center”, we select the branch which corresponds to the current view point and the branch which is one level behind. Anatomical names of the selected branches are displayed in the virtual bronchoscopy image by character string in English at the positions corresponding to the selected branches. When the viewpoint and the view direction are changed, the name of branch and its displaying position are also changed.

4 Experimental Result and Discussion

4.1 Automated Labeling of Bronchial Branches

We applied the proposed method to eleven cases of real 3-D chest X-ray CT images which were taken by helical CT scanner. Image specifications are follows : image size is 512 (pixels) x 512 (pixels), the number of slices is 60 - 118 (slices), pixel size is 0.63mm, reconstruction pitch is 1mm or 2mm, width of X-ray beam is 2mm or 5mm. Knowledge base was created manually from textbook of anatomy. As the evaluation items for assignment, we used the parent name and the direction of the branch. Fig. 7(a) displays the outside view of bronchus extracted from CT image. Fig.7 (b) is the thinned results of the extracted bronchus region. Fig.7 (c) shows the tree structure and assignment results of anatomical names. Table 1 shows the results of assignments. The experimental result showed that this methods can assign correct anatomical names to about 90% of the extracted branches. This methods is considered as one of the method which uses knowledge based processing for medical image processing. This method will be very useful for automated description by anatomical name of the lung cancer extracted automatically [13].

4.2 Automated Display of Anatomical Name in The Virtual Bronchoscopy System

Fig.8 shows the scene of displaying the branch name in the virtual bronchoscopy system. Anatomical names are appropriately selected and automatically displayed on the images rendered by the virtual bronchoscopy system. Frame rate was about 6 frames / second. The computer was Silicon Graphics Octane MXI (cpu :R10000 195MHz, main memory: 512MByte). We confirmed that automatic display of branch name is very useful for understanding the current observation location.

The proposed method enables to display anatomical name on the endoscopic image rendered by the virtual bronchoscopy system. This is one of new diagnosis systems of medical images, which combines the observation method of 3-D medical images and the implementation of the knowledge based processing. Furthermore it is especially useful for education of medical students who are learning branching structure of the bronchus. Authors are collaborating with medical doc-

Fig. 6. Selection of the bronchial branches for displaying anatomical name

Fig. 7. Results of automated assignment of the bronchial names. (a) the extracted region of the bronchus, (b) the thinned result, (c) automated assignment result of the branch names

Table 1. Results of automated assignments of the anatomical name of bronchial branches

Data No.	The number of branches extracted from CT images	The number of branches assigned by proposed method successfully
001	28	24
002	27	23
005	9	9
006	9	9
007	19	19
010	19	15
014	9	9
018	11	11
019	11	11
021	43	43
024	23	7

tors for application of the proposed method to the education at medical college (Fig.9).

5 Conclusion

This paper presented the automated assignment method of anatomical names basing upon the knowledge base for bronchial branches, and its application to the virtual bronchoscopy system. Future work includes evaluation by large number of cases, development of assignment algorithm which can treat variation in the shapes of bronchus among patients efficiently, applications to other organs, and extension of the knowledge base.

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Fig. 8. An example of the images of automated display of anatomical names in the virtual bronchoscopy system. (a)-(d) are rendered at different viewpoints and from different view directions.

Fig. 9. Scenes of using the proposed system for education of medical students (at Sapporo Medical University, Japan)