A 3D MODEL OF THE HUMAN LUNG WITH LUNG REGIONS CHARACTERIZAITON

Tatjana Zrimec[1,2], *Sata Busayarat*[2], *Peter Wilson*[3]

[1]Centre for Health Informatics,
[2] School of Computer Science and Engineering
University of New South Wales
[3] Pittwater Radiology
Sydney, Australia
{tatjana,satab}@cse.unsw.edu.au

ABSTRACT

A method for modelling human lungs is presented. The model includes both knowledge of lung anatomy and knowledge of the appearance of objects in High Resolutions CT images of the lungs. Symbolic, structural and geometric information in the model is stored in Frame structures. Frames allow easy representation of the hierarchical structures that are found in human anatomy. A few anatomical landmarks are determined and used for lung characterization as clinically meaningful regions. The results from automatic landmark segmentation, tested on 1685 images from 84 patient studies, show that the carina, hilum, spinal cord and sternum are quite stable features across patients. The use of anatomical landmarks and lung regions helps the system to deal with image and human variability.

1. INTRODUCTION

The number of images available to radiologists is growing rapidly and has outpaced the human abilities to process them. Computational aids are required to filter the large number of images and to focus the radiologist's attention on diagnostically interesting patterns. Model based approaches offer a possible solution to automating the process of image interpretation. They use the knowledge of expected objects in a scene to recognise those objects if the objects appear in an image. In medicine, model based approaches are quite popular since there exists a well structured, large body of knowledge about human anatomy, and the images have to be interpreted using same medical language and terminology as used by radiologists and physicians. There is a large number of model-based systems that use different types of models, different implementations and different approaches to image interpretation [1-5]. The models are often represented as semantic nets [3, 4] or in a form of 3D anatomic atlases [6]. As the success of a model-based system depends largely on the knowledge and its representation, there are still many challenging problems.

In this paper we present our approach to modelling of human lung anatomy, which results in a model that is used for automatic image interpretation of HRCT images. The model includes both a symbolic representation of the domain knowledge and a representation in a form of a 3D atlas. The symbolic representation includes knowledge of the relationships between objects. The atlas that is built from segmented HRCT images of the modelled anatomy contains objects described in terms of image attributes. The relationships among objects in the 3D model are represented using a spatial coordinate system.

Typically, radiologists characterize lungs as being divided into several regions: central vs peripheral, upper vs lower, anterior vs posterior and unilateral vs bilateral. The reason is that many lung diseases show specific regional distributions or preferences. The same abnormal findings located in different regions of the lung or distributed in a different way can be linked to different pathologies [7]. There are several reports on dividing the lung into lobes and lung segments. A few authors [8] have used the pulmonary fissures to divide the lung into lobes. More recently, there are reports on dividing the lungs into segments using a semiautomatic method [1] or automatic nomenclature labelling [6]. However, there are no reports on methods for characterizing lung regions that are used in clinical reporting.

This paper presents an automatic method for lung region characterization in HRCT images based on anatomical landmarks. The landmarks: sternum, vertebrae, spinal canal, carina and hilum are used to identify the regions: central lung, peripheral lung, upper lung, lower lung and anterior lung, posterior lung. The landmarks and the lung regions are used to improve the mapping of the patient data to the model.

0-7803-8554-3/04/$20.00 ©2004 IEEE.

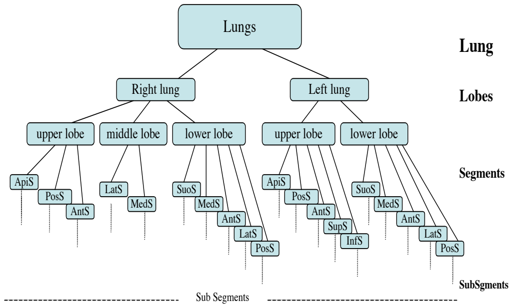

Fig. 1. Lung hierarchy

2. MODELLING AND REPRESENTATION

An anatomical model should have the ability to encode the shape of anatomical features and to include normal cases and variations [5]. The model must be easy to understand, must allow easy validation and must be applicable to different imaging modalities. To assist image processing, a model should include knowledge at both the image level and the anatomical level. With these requirements in mind we determine what is to be represented and how [5].

At the anatomy level, the knowledge includes descriptions of the imaged objects and features and the relations between them. At the image level, the knowledge includes information about the expected appearance of an anatomical feature in an image. We use a Frame representation where object classes are organised in an “is-a” hierarchy [3-5]. Frames allow easy representation of the hierarchical structures that are found in the human anatomy. For example, the lungs are divided into left and right lung. Each lung is divided into lobes and each lobe into bronchopulmonary segments. Each lung segment is divided further into sub-segments. As is shown in Fig. 1, “there is a clear definition of the spatial division of the lung” [6]. It is also important to incorporate the different appearances of the modelled structures from different views, similar to those produced by the imaging modalities. The frame system can describe a scene from different viewpoints. The following frame types represent the domain knowledge:

Anatomy frame – stores anatomical information about the properties and organization of the lungs and surrounding anatomical structures (for example, spine, lungs, mediastinum, trachea).

Structure frame – stores information of the lung, bronchi, vessels, lymph and other hierarchical structures (for example, the lung hierarchy in Fig. 1.).

Spatial frame – stores 3D spatial organization and spatial relations of the lung features (apex, hilum, base, borders and surfaces).

Volume view frame – contains a description of a set of axial images as produced by HRCT. Average intensity and other image attributes are attached to each expected object in the image.

2D view frame – stores a set of description of standard projections of the lungs: lateral view and anterior posterior view, as produced by X-ray.

Pathology frame, stores knowledge of diseases patterns, pattern’s size and shape and their expected location and distribution in the lungs.

The frames are organized in different hierarchies and are all linked together to enable automatic image interpretation.

Due to the variability in human anatomy, a model in the form of a 3D atlas cannot be directly mapped to patient data. However, using landmarks, with relatively stable position on an image, enables a model to be “mapped” to patient data and to facilitate image segmentation and interpretation. The mapping can be significantly simplified, if the models are divided into regions. Consequently, we were looking for landmarks that will enable division of the lungs into clinically meaningful regains.

3. LANDMARKS SELECTION AND SEGMENTATION

Anatomical landmarks are reference objects or features that are often used by physicians to help determine the location of the imaged part of the body. Those landmarks should be consistent despite variations in the patient’s position during scanning, or changes due to disease progression [1]. Selection of a good set of anatomical landmarks is essential for model-based image interpretation.

We have chosen the *sternum*, and the *vertebrae* with the *spinal canal*, as the main landmarks for lung region detection. The sternum and the vertebrae are good anatomical landmarks, because they are bones and their position is relatively fixed within the chest. The sternum and the vertebrae have been used before for a different task, namely for inter-patient image registration [1, 4]. Additional landmarks were chosen: the *trachea,* which is often used by radiologists, the *carina*, the place where trachea bifurcates into two main bronchi and the *hilum.* The *hilum* defines the base of the lung, which is, comparable between patients. To date there are no other reports on hilum detection and usage for image interpretation.

Once the landmarks are segmented from HRCT images, they can be used for detecting lung regions. Since lung regions are required for each patient study, we have developed automatic methods for landmark segmentation and lung region characterization.

3.1 Sternum and Vertebrae Segmentation

The sternum and the vertebrae are bones within the chest (see Fig. 2-a) with densities (~1000 Hounsfield units (HU)) that are significantly higher than the surrounding soft tissue (30-40 HU). To separate bones from the surrounding soft tissue and the lungs, we apply a threshold of 300 HU. The resulting binary image is post-

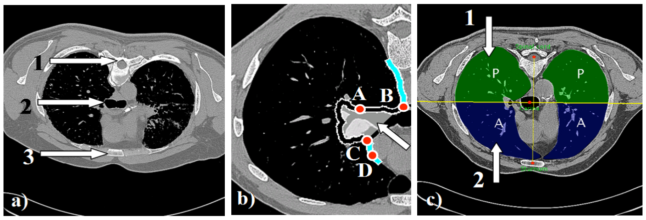

Fig. 2: a) 1-spine, 2-carina, 3-sternum, b) hilum region B-A-C, c) Lung regions: 1-posterior and 2-anterior.

processed using morphological operators (binary erosion and dilation operators) to smooth the detected boundaries and to remove noise. After connected component labelling, the sternum and the vertebrae are distinguished from the other bones by using knowledge from the model. The *anatomy frame* and the *volume view frame* provide knowledge about the position and size of the sternum and vertebrae in an image.

The spinal canal is segmented by using the centre of the smallest circle inside the vertebrae region. The spinal canal is a more accurate landmark than the vertebrae, because it has less variation in size and shape.

3.2 Trachea Segmentation and Carina Detection

The trachea appears as a circular black object located in the middle of the body contour. To segment the trachea in an HRCT image, a fixed value of -400HU threshold is applied. After morphological filtering and connected component labelling, the trachea is segmented using knowledge from the model about its expected location and size. The model also provides knowledge of similar structures that is applied during trachea segmentation. The reason is that the oesophagus has similar appearance as trachea in an image and can be misclassified as the trachea.

The trachea is traced until the point at which it starts to bifurcate into two main bronchi. The carina is the position where the trachea starts to bifurcate (see Fig. 2-a). In a sparse scan (with 15mm gap between consecutive slices), the exact location of the carina may not be visible. In that case, the slice before the trachea bifurcation is used as the carina position.

3.3 Hilum Detection

The hilum is a wedge-shaped depression of the mediastinal surface of each lung, were the structures forming the root of the lung enter and leave the lung [9]. The root consists of the main bronchi, pulmonary vessels, lymphatic vessels and nerves. In HRCT images, the hilum appears in the mediastinum as a high-density structure covered by low-density lung parenchyma (see Fig. 2-b). The hilum starts slightly above the carina. The hilum ends approximately at the end of the sternum. Consequently, the search for the hilum is narrowed to a few scans.

The method for hilum detection is based on curvature analysis of the lung boundaries and proceeds as follows. Before lung segmentation, the main bronchi are removed from the image to enable lung parenchyma detection. Sometimes the main bronchi are close to the lung parenchyma and have similar appearance. The lungs are segmented using active contour snakes and morphological operators [10]. As the hilum lies in the mediastinal part of the lungs, only the inner part of the lung boundaries that is closer to the trachea is considered as a potential hilum region (hilum ROI). A curvature analysis is performed in the hilum ROI to detect the most concave curved section of the lung boundaries. Four points (two on each side), with maximum slopes that are close to the section with maximum curvature, are chosen as candidates for hilum end points (see Fig, 2-b, A, B, C, D). Two of those points are selected to be the hilum end points by using heuristic rules. The rules use, among other information, the relative position of the points in respect to the medial axes. The hilum region represents the part of the lung boundary (B-A-C) that lies between the selected "end" points (see Fig, 2-b, B and C).

4. RESULTS

The current prototype model consists of three segments: a set of *lung structure*, lung *spatial* and *volume view* frames and a 3D atlas of the human lung. The 3D atlas was developed using a full set HRCT volume data with 418 images. The images were pre-processed and the lungs were segmented automatically using active contour snakes and morphological operators [10]. Other lung anatomy features: the fissures, the bronchi and the vessels were segmented semiautomatically. The atlas is used for evaluation of the automatic methods for fissures, bronchi and vessel detection. The lung fissures (see Fig. 3-a) are used to divide the lung into lobes.

The methods for automatic landmark segmentation were tested on 1685 images from 84 patients, one study per patient. Each study covers the entire lung with a 15mm gap and 1.0mm slice thickness. From the results presented in Table 1, we can see that the chosen landmarks are very stable across patients.

Landmark	Trachea	Carina	Sternum	SpinalCanal	Hilum
Accuracy	100%	99%	99%	96%	93%

Table 1: Results from landmarks segmentation in 84 cases

The landmarks were used to characterize different lung regions as follows. The hilum was used to divide the lungs into apex, medial and base regions. The images above the hilum belong to the *apex* of the lung, the images in the region of hilum belong to the *medial* region of the lung and the images bellow the hilum belong to the *base* of the lung (see Fig. 3-b). Position of the root of the lung, where the bronchus enters the lung, is used to divide the lung into c*entral, medial* and *peripheral* regions. Each lung is divided into three equal parts

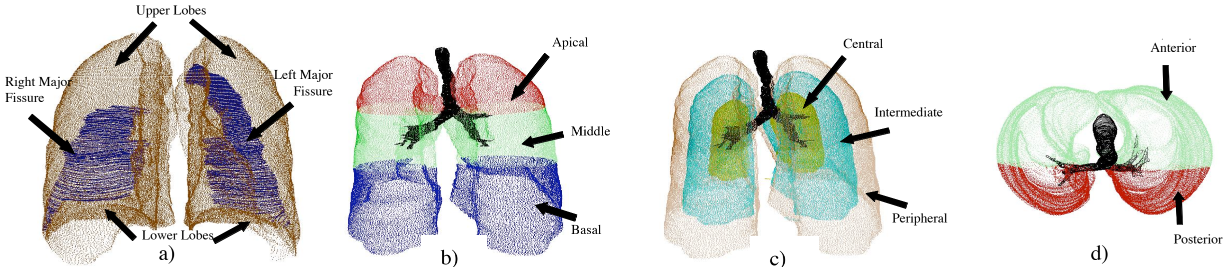

Fig. 3: A 3D model of the human lung; a) Fussers and lobes; Regions: b) apex - basal, c) central - peripheral, d) anterior - posterior

starting from the root to the periphery of the lung (see Fig. 3-c). The sternum and the spinal canal are used to define the medial plane that divides the lungs into left and right lung. *Anterior* and *posterior* regions of the lung are determined by using the vertical plane that runs through the centre of the carina and it is perpendicular to the medial plane (see Fig. 3-d). For the purpose of HRCT image interpretation, the lung regions are mapped to each 2D axial image (See Fig. 2c).

6. CONCLUSIONS

We have presented our approach to building a 3D model of the human lung that enables automatic interpretation of HRCT images of the lungs. The model stores symbolic, structural and geometric information about lung anatomy that is necessary to guide image analysis and interpretation. For more accurate mapping of the model to patient data, a set of anatomical landmarks is determined and the lung is divided into lung regions. Knowledge-based methods for automatic landmarks segmentation and lung division have been devised and tested. The test results show that the carina, hilum, spinal canal, vertebrae and sternum are quite stable features across patients.

Our methods for sternum and vertebrae detection differ from the one proposed in [1], since they use attenuation-based template matching. Our method for spinal cord segmentation is similar to the one proposed in [4], where a knowledge-based approach and a task-oriented architecture were used. However, the work presented here differs from existing work in that we have used the landmarks for lung region characterization instead of point registration. The modelling approach proposed here differs from the one proposed in [6] in that we are developing a complete lung model that includes both anatomical information in the form of a symbolic model and a 3D atlas. It is similar, to some degree, to the approaches proposed in [3] and [4].

The novelty of our approach is in determining stable landmarks and characterization the 3D model of the lung into lung regions. The lung regions and the landmarks enable more accurate mapping of the model to patient data as well as inter and intra patient image mapping. The lung prototype model with the 3D lung atlas is currently used to assist automatic features segmentation and for the evaluation of the methods for automatic lung features detection.

Acknowledgement

We thank Michael Jones for his medical knowledge and Claude Sammut for his comments on the paper. This research is supported by the Australian Research Council.

7. REFERENCES

[1] M. Betke, H. Hong, et al, “Landmark Detection in the Chest and Registration of Lung Surfaces with an Application to Nodule Registration.”, *Med. Image Anal.*, **7**(3), pp. 265-281, 2003.

[2] S. Krass, D. Selle, et al, “Determination of bronchopulmonary segments based on HRCT data”, In: Lemke HU, et.al., eds. *Computer Assisted Radiology and Surgery*. Elsevier, pp. 584-589, 2000.

[3] M. S. Brown et al., “Knowledge-based segmentation of thoracic computed tomography images for assessment of split lung function,” *Med. Phys.*, **27**(3), pp. 592–598, 2000.

[4] N. Archip, P.J. Erard, et al.,“ A knowledge-based approach to automatic detection of the spinal cord in CT images”, *IEEE Trans. Med. Imag.,* **21**(12), pp. 1504-1516, 2002.

[5]. T. Zrimec, C. Sammut, “A Medical Image Understanding System”, *Eng. Appl. of Artif. Intell.* **10**(1) pp. 31-39, 1997.

[6] B. Li, E.G. Christensen, et al., “Establishing a Normative Atlas of the Human Lung: Intersubject Warping and Registration of Volumetric CT Images”, *Acad Radiol*, **10** pp. 255–265, 2003.

[7] R. W. Webb, N. L. Muller, and D. P Naidich: High-Resolution CT of the Lung (third edition), Lippincott Williams & Wilkins, 2001.

[8] M. Kubo, N. Niki, et al, “Extraction Algorithm of Pulmonary Fissures from Thin-section CE Images Based on Linear Feature Detector Method,” *IEEE Trans. Nucl. Sci*, **46**, pp. 2128-2133, 1999.

[9] K. L. Moore, A. F. Dalley, "Clinically Oriented Anatomy (4th edition)", Lippincott Williams & Wilkins, 1999.

[10] J. Papalousis, “LMIK – Anatomy and Lung Measurements using Active Contour Snakes”, *Undergraduate Thesis*, CSE,UNSW, Sydney, Australia, 2003.