**Lung segmentaion**

\citep{kalender1991semiautomatic,kemerink1998segmentation,leader2003automated,armato2004automated}

2D thresholding lung segmentation

it may cause incontinuity between slices, time comsuming

\citep{keller1981automatic,hedlund1982two,hoffman1983noninvasive,hoffman1985effecta,hoffman1985effectb}

early-stage thresholding-based lung segmentation methods

usually combined with much manual interaction, too time consuming and cause too many personal errors

\cite{hu2001automatic}

the first research group to apply threshold-based algorithm in a fully automatic lung segmentation method

Instead of a fixed threshold value, an optimal thresholding method was used to automatically choose a threashold value, left and right lungs were then separated by identifying the anterior and posterior junctions by dynamic programming, Finally, a sequence of morphological operations was used to smooth the irregular boundary along the mediastinum.

\cite{ukil2005smoothing}

a further improved automatic lung segmentation method for the three-dimensional smoothing of the lung boundary using information from the segmented human airway trees.

First, a bounding box was defined around the mediastinum for each lung using the information from the segmented human airway trees, and all operations were performed within the bounding box. Then, all generations of the airway tree distal were defined to the right and left main stem bronchi to be part of the respective lungs and all the other segmented structures could be excluded. Finally, a fast morphological closing with an ellipsoidal kernel was performed to smooth the surface of the lung.

\cite{sun20063d}

an anisotropic filtering method was firstly applied on \gls{ct} slices to enhance the signal-to-noise ratio. A wavelet transform-based interpolation method was subsequently used followed to construct the 3D volumetric \gls{ct} slice data with volume rendering. After that, an adaptive 3D region-growing algorithm was developed to detect lung region, combined with automatic seed-locating methods. Fuzzy logic algorithms and 3D morphological closing approaches were finally used to refine the lung volume and fill the holes in it.

\citep{kitasaka2003lung}

To deal with the problem of lesions adjacent to the chest wall and mediastinum

developed a lung area extraction method using a shape model

A contour shape model using a B\'ezier surface was fitted to the contour surface of the individual input images with an affine transformation method. Then, an active contour model was utilized to refine the initial segmentation.

lesions adjacent to the lung apex or diaphragm could result in segmentation errors

Lung segmentation

\citep{pu2008adaptive}

presented a lung segmentation algorithm based on adaptive border marching (\gls{abm}) to include juxtapleural nodules in the lung region since these juxtapleural may be excluded from the results calculated by a conventional threshold-based algorithm. The adaptive border marching algorithm could smooth the lung borders after a initial thresholding processing and minimize oversegmentation of adjacent regions such as the abdomen and mediatinum at well.

\citep{pu2011shape}

In order to deal with the problem of various diseases, image noise or artifacts and individual anatomical variety

developed a shape analysis strategy termed ''break-and-repair''. A principle curvature analysis was applied to eliminate the problematic regions and then radial basis function (RBF) based implicit surface fitting was used to get a smooth lung surface.

\citep{prasad2008automatic}

To overcome the problem of error detection for lung pathologies

made use of the rib curvature information to help with finding the lung borders. The method was based on a threshold-based algorithm followed by morphologic operation and the core principle of the method was adapt the threshold value to individual subject by making the curvature of lung along the ribs be similar to the curvature of the ribs. The curve of the ribs and lung boundary were both represented by polynomial interpolation even though there was minimal deviation from this representation.

\citep{wang2009automated}

proposed a texture analysis-based method for accurate segmentation of lungs with \gls{ct} scans. The lung region including normal and mild ILD lung parenchyma was first segmented by a CT value thresholding technique and then texture-feature images derived from the co-occurrence matirx was used to identify abnormal lung regions with severe ILD from the initial results. 2D holes filling was applied to smooth the final lung segmentation.

\citep{sun2012automated}

In the first step, a robust active shape model (\gls{rasm}) matching method was utilized to roughly find the outline of the lungs. To initialize the shape model of RASM, the detected rib information was used subsequently. In the second step, an optimal surface finding approach was applied to further adapt the initial segmentation result to the lung.

**Fissure detection**

\subsubsection{Anatomy knowledge based method}

Methods aiming at detecting the lobar fissures usually start by finding an approximate location of the lobar borders based on prior anatomical knowledge of lung structures to narrow the search area for fissure detection \citep{kuhnigk2003lung,kuhnigk2005informatics,zhou2004automatic,saita2006algorithm,zhang2006atlas,ukil2009anatomy,pu2009computational,lassen2010automatic,doel2012pulmonary}. A number of published papers use the segmentation results of airways and vasculature to help with localizing the fissures. Usually, the vasculatures segmentation provides more accurate estimation of lobar fissure locations than the airway trees, since more vessel generations can be detected on \gls{ct} scans and these vessels span the entire lung volume which can help us find complete gaps between lobes. However, airways also play an important part in initial estimation of fissures, since airways trees can be more reasonable divided into lobar branching while the structure of vasculature branching is more complicated and some connections are hard to separated accurately. Therefore, a lot of studies take advantage of airways to label each lobar branching and then get the guessing fissure locations based on vasculature information.

\cite{kuhnigk2003lung,kuhnigk2005informatics} was early group to present a framework of making use of lobar airways and vasculature into account for automatic fissure detection. A watershed transformation method was used to take an analysis of these anatomical structures and this method was widely used and improved by other researches later, but the results with the simple algorithm was still inaccurate even for some clearly visible fissures.

\cite{ukil2009anatomy} developed Khnigk's fissure detection method which combined a distance transform to segmented vessels and original chest CT scan as a cost image for a watershed transform guided by airway and vascular markers. The improved watershed transform algorithm could provide a close initial approximation to the lobar fissures and an initial search area for the lobar fissures was determined. Subsequently, a further refinement method was used to construct a region of interest (\gls{roi}) encompassing the fissures and a 3D optimal surface detection algorithm combined with a ridgeness measure based on the structure tensor analysis was then applied to enhance the \gls{roi} and finally find the optimal surface within the ROI. In the last step, incomplete fissures were smoothly extrapolated using a fast-marching method based segmentation of a projection of the optimal surface. The method was evaluated by comparing the automatic results to manual tracings of the fissures with 12 normal subjects and 17 diseased subjects. The RMS errors for the left oblique fissure, right oblique fissure and right horizontal fissure were 1.81, 1.57, 1.43mm respectively of the normal subjects and 1.71, 1.88, 2.31 respectively of the abnormal subjects. However, some manual operations were still needed for about 20\%-25\% subjects.

\cite{lassen2010automatic} also described the fissure detection method by building a cost image for the watershed transformed segmentation which is an extension of the framework of Kuhnigk. The interactive segmentation method was tested on 25 \gls{ct} scans comparing to a manual segmentation by a human observer and showed an average distance of 1.57$ \pm $0.3mm.

In addition, \cite{zhou2004automatic,saita2006algorithm} took advantage of the linear appearance of fissures to class the vessels and bronchi into five lobe regions using an edge detection method and the Hough transform based curved surface detection method, respectively.

\subsubsection{Shape based analysis method}

Generally, lobar fissures can be regarded as bright planes crossing the pulmonary volume because of the higher density value of fissures comparing to the surrounding tissues. Based on this information, quite a number of published methods use local filtering algorithm to detect the voxels which lie on these planes, so that these detected voxel points can construct a continuous fissure surface. In 2D space, the fissure appears as a clear curve, therefore some early papers usually detected fissure points based on gray-level information in 2D space. For example, \citep{wang2004shape,wang2006pulmonary} presented an approach for segmenting the major fissures on \gls{ct} scans based on shape information. The fissure was initially denoted as a curve based on the prior knowledge of the shape of the fissure to identify the surrounding region of fissure, called ''fissure region'' for subsequent automatic segmentation. Next an image transformation called ''ridge map'' was proposed for enhancing the appearance of initial fissures. The shape-based curve-growing growing method modeled by a Bayesian network could then be applied to this ''map'' to segment the fissure. The method was applied to segment the fissures of chest \gls{ct} of 10 patients with pulmonary nodules. The result showed that only 2.4\% of the fissures required manual correction and the average distance between the automatic and manual segmented fissures was 1.01mm.

In 3D space, the most common used method to detect these pulmonary fissure plane structures is taking an eigenvalue analysis of Hessian matrix \citep{frangi1998multiscale,wiemker2005unsupervised,kitasaka2006recognition,ochs2007automated,van2008supervised,lassen2011interactive,lassen2013automatic,ross2010automatic,doel2012pulmonary}. \cite{frangi1998multiscale} was the first to present eigenvalue analysis of Hessian matrix to detect plane structure such as fissure and tube structure such as vessel on \gls{ct} images. The three eigenvalues of Hessian matrix gives a fissure probability for each voxel and the relation between the eigenvalues of the Hessian matrix describes the local image structure. \cite{wiemker2005unsupervised} was also an early paper to use Hessian matrix for fissure detection and two 3D filter approaches were proposed in this paper. The first filter was based on first derivatives of the image gray values and utilized the eigenvalues of the local structure tensor. The second filter was based on second derivatives and utilized the eigenvalues of the local Hessian matrix.

\cite{ochs2007automated,van2008supervised} both used a pattern recognition approach to detect pulmonary fissures combined with eigenvalue analysis of Hessian matrix as feature and classification was also performed on these fissures. \cite{lassen2011interactive,lassen2013automatic} utilized the eigenvalue analysis of Hessian matrix based on the initial approximation fissures from anatomical structure of airway and vessel trees. This algorithm combined with two types of methods could reduce many false points since the first anatomic-based method could find a region of interest which made the analysis of Hessian matrix only work in the surrounding area of the initial guessing fissure locations. Subsequently, morphological operations such as direction-based connected component analysis were also used to further reduce some non-fissure points. The average distance between automatic fissures and the reference for 55 \gls{ct} scans were 0.98mm, 3.97mm and 3.09mm for the left oblique fissure, right oblique fissure and right horizontal fissure respectively.

\cite{ross2010automatic} proposed a particle system that sampled the image domain combined with Hessian matrix to get a set of candidate fissure locations. A maximum a posteriori (\gls{map}) estimation was followed to eliminate false candidate points and a post-processing operation was applied to remove remaining noise points. A thin plate spline (\gls{tps}) interpolating surface fitting method was lasted performed to form the finial fissure surfaces. \cite{doel2012pulmonary} also made use of both anatomy knowledge based method and Hessian matrix to find a set of fissure candidates and proposed a smooth multi-level B-spline curve through the fissure points and extrapolated to the lung borders to get the fissure surfaces.