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Automatic lung fields segmentation in CT scans using morphological operation and anatomical information

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Abstract. Segmenting lung fields from CT (Computed Tomography) scans is an important task for the analysis, diagnosis and treatment of pulmonary diseases. Although many segmentation methods have been presented, some new automatic segmentation methods for the lung fields are still proposed for the CT scans. This paper proposes a novel segmentation method for lung fields by using morphological closing operations and thresholding for normal lungs in CT scans. Additionally, under the guidance of anatomic information, the lung fields could be well segmented with lobar fissure, thin junction between the left/right lung fields, indentation of the blood vessels and bronchi-walls. This experiment is performed by employing the thoracic CT scans datasets, and it is proved to be an effective method.

Keywords: Segmentation, morphological operation, junction region, lung fields, lobar fissure

1. Introduction

X-ray computed tomography (CT) is a commonly used imaging technique for the detection of lung diseases. In general, lung segmentation, as the first step for quantitative analysis and computer-aided diagnosis [1,2], determines the success or failure of further analysis. However, manual segmentation is laborious. Since the number of scans has increased tremendously with the application of multi-slice spiral CT scanners, it is critical to develop more accurate and automatic algorithms to identify lung fields. As the contrast of the junction region of the left/right lung fields is reduced by the volume averaging or partial volume effect, the junction might disappear on the anterior/posterior of the lung fields when segmented based on a global CT value threshold. Some methods have been used to separate the attached left/right lung fields, such as the methods based on the graph-research and watershed preprocessing [2-4]. The indentation of the lung fields might be produced by blood vessels and bronchi walls or abnormal areas in the threshold segmentation. This problem was solved by the curvature ratio based boundary connecting [3], rolling-ball smoothing boundary of the lung fields. The adjacent CT scans borders marching [5] and registering [6] got the similar boundaries of lung fields. The rib curvature constraining boundary fitting found the smooth boundaries [7], and the stochastic frame composed of the LCDG and MGRF [8] and the texture analysis based methods found the

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boundaries from local detailed information of the lung fields [9]. All in all, they were trying to find out the correct boundaries to segment out lung fields in CT scans. As the anatomical information including expected volume, shape, relative position, chest wall, and X-ray attenuation of tissues provides some feature constraints, the information-based approaches may discriminate the tissues structures of similar attenuation and anatomic continuity better. Therefore, this paper proposed an automatic method that the anatomical information combines with threshold segmentation and morphological operation. Procedures of the method are described in section 2 and the experimental results are described in section 3. Finally, section 4 presents the discussion and conclusions.

2. Methods

Steps of the proposed method are as below:

(1) filter the scans by the composition filter;
(2) segment the thoracic scans initially by the threshold method (CT value: -500HU) , and then fill the holes with the region filling;
(3) separate the attached lung fields;
(4) acquire initial masks by the centroid and the anatomical knowledge of lung fields;
(5) join the regions of the masks separated by lobar fissures;
(6) smooth the boundaries of the left/right masks by morphological closing operation;
(7) segment out lung fields in the original CT scans by the masks.

According to the above procedures, the lung fields could be correctly segmented out from the thoracic CT scans, and more details will be discussed in the following sub-sections.

2.1. Filtering and initial segmenting

Low-dose CT scans are strongly affected by the imaging noises, thus they should be firstly filtered for subsequent analyzing and processing. The structure of the proposed composition filters is shown in Fig. 1. The Gaussian filter smoothes the lung region, and then the wiener filter and the median filter which have the ability of the preserving objects edges reduce the noises of the thoracic scans.

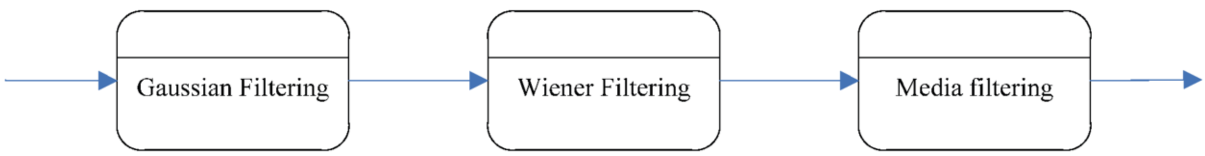

Fig. 1. Flow of the filtering procedure

A thoracic CT scans can be divided into three regions: the outside of scanning range, the outside and inside of the chest wall. In the chest wall, a global segmentation threshold has been chosen as (1).

$$M(x,y)=\begin{cases}1 & p(x,y)\geq CT\_thresh \\ 0 & otherwise\end{cases} \qquad when\ p(x,y)\in\Omega_{in\_T} \tag{1}$$

Where $p(x,y)$, $M(x,y)$ and CT_thresh denotes the input of CT scan, the corresponding output of masks and the preset threshold respectively.

2.2. Anatomical information and masks acquiring

After the noises are reduced by the filter, anatomical information is introduced to segment the CT scans. It is stated explicitly in terms of attenuation threshold, shape, continuity and relative position, and it is briefly described as below:

(1) the main trachea exists on the apexes of lung;
(2) the scanning region of the thoracic scans can be divided into two regions by the chest wall;
(3) the area of lung fields is larger than the constant value in general, and the centroids of those shapes locate in a range of horizontal and vertical coordinates;
(4) some left/right lung field might have thin junction, where the intersection is located in the middle parts of lung;
(5) the blood vessels and bronchial walls appear at the indentions of lung fields in the hilus.

The initial masks are acquired by CT value threshold based segmentation and the anatomical information. When the scan locates in the upper parts of the lung, the linear structure element B would be used to separate the main trachea. As in Formula (2), the scan region A is morphologically eroded to be separated into two regions: trachea A_1 and lung field A_2.

$$A \,\Theta\, B = \{z \mid (B)_z \subseteq A\} => A_1 \cup A_2 \tag{2}$$

Firstly, when the region area is less than the pre-set value or the row coordinate of the region centroid doesn't meet the range conditions, it would be ignored in the choice of the initial masks. In the remaining regions, the max of the left/right region can be chosen for initial masks respectively when the centroid coordinates C_{row} and C_{col} meet such conditions as below:

$$init\_LF = \begin{cases} LF_{left} & C_{col} \le pre\_LC_{col} \quad C_{row} \in [\min\_row, \max\_row] \\ LF_{right} & C_{col} \ge \mathrm{Pr}e\_RC_{col} \quad C_{row} \in [\min\_row, \max\_row] \end{cases} \tag{3}$$

Where LF_{left}, LF_{right} is the left/right region respectively, $init\_LF$ is the chosen main region. Some statistical information has been obtained as part knowledge in the anatomical information. The row and column coordinate ranges of the region centroid are used as rules to extract the correct masks.

The boundaries of the lobes are lobar fissures, the regions separated by which should be considered as a whole lung field. The separated regions are joined by closing operation; meanwhile, small indentations of the lung fields are smoothed preliminarily. The intact masks are obtained as shown in Fig. 2.

Fig. 2. Join regions into an intact lung field

After the CT value of the thin anterior/posterior junction region is reduced by the region averaging or smoothing, the CT attenuation of the interface tissue might fall into the range considered as lung field. Thus, the threshold segmentation would make the junction disappear. According to the anatomical information, when the area of the current mask is one third larger than the previous area, the segmentation leaks into another lung field already. Therefore, a separate procedure is used to divide the region into the left/right regions. However, with the previous filtering schema in the initial segmentation, the detailed information is smoothed and the interface of the thin soft tissue is blurred, thus it is very difficult to separate the left/right lung fields. As a result, a small-scale Gaussian filter with the kernel size 3*3 would be reused for the original scans filtering, and then the region located in the anatomic information is cropped. As the interface tissue has a slightly higher CT value than the lungs in usual and the lung fields have the continuous junctions in the adjacent scans, the cropped region has enough detailed information to distinguish the junction of lung fields, in which the boundaries tracing algorithm can find the junction. The separate results are shown in Fig.3. And based on the area rule of the regions the small region of the airway would be discarded in the next step of the proposed method.

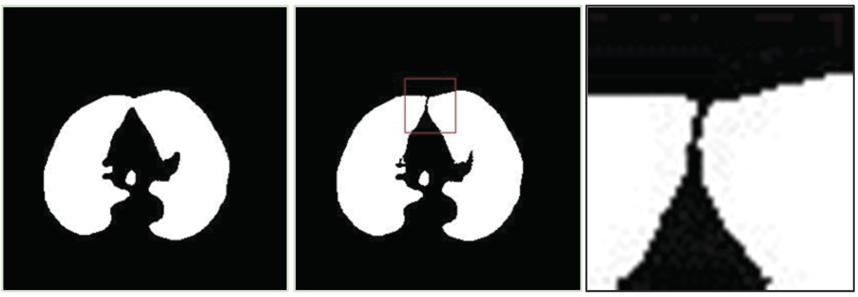

Fig. 3. Intersection region separation

2.3. Mask boundary smoothing

In the anatomic information, an individual lung field can be taken as an object with smooth boundaries. Based on the characters of lung fields, their boundaries will be smoothed by morphological closing operation. The max radius of the disks used for the lung fields smoothing is assumed as $CR_{closing}$, and it is set as the max curvature radius of the mediastinum boundaries of the lung field. The radius of other disks would vary with the scan change as (4). However, when the computed radius is bigger than the minimum distance between the borders of the mask regions and the scan, the closing operation would get the error results. In order to solve this problem, choosing the disk radius should follow as (5).

$$mRadius = (i - position) * close\_Rad \tag{4}$$

$$\begin{aligned} l\_dis &= \min(L_1, L_2, L_3) \\ r\_dis &= \min(R_1, R_2, R_3) \end{aligned} \tag{5}$$

Where the L_i, R_i (i=1,2,3) is the shortest distance between the mask and the left or right border of the scan respectively.

$$\begin{aligned} l\_Radius &= \min(l\_dis, mRadius) \\ r\_Radius &= \min(r\_dis, mRadius) \end{aligned} \tag{6}$$

As previously described, the final radiuses of the close operation have been settled down as (6).

3. Experiment and results

The CT scans of ten subject cases were acquired by a MDCT scanner (GE light-speed ultra) at 120 kVp and 100 mA, and the scan size is 512 by 512 (16bits depth) pixels. Their thickness is 1.25 mm and the frame size on the CT scan is 390 by 390 mm and each case has scans about 209 to 304, but the mean scans of the effective lung fields is only about 220.

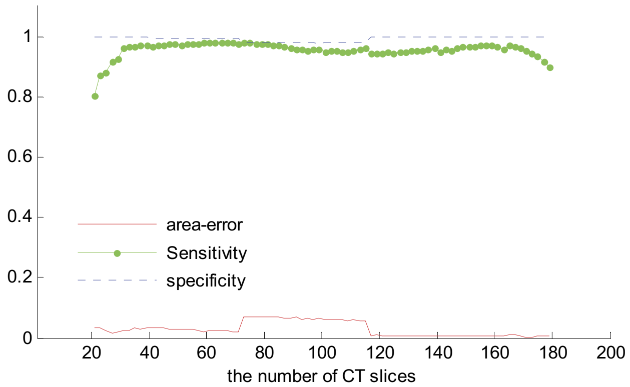

Fig. 4. Evaluation of the segmented lung fields

In the experiment, the horizontal coordinate has been preset as less than 220 pixels and greater than 280 pixels respectively; the vertical coordinate is among the location approximately varying from 240 to 300 pixels. By following the processing procedure, the segmentation results are obtained. To evaluate the performance on CT scans, the results are compared with the golden-standard. It is determined by three radiologists, each of which defines the lung boundaries to segment out the lung fields with an interactive platform. The sensitivity and specificity [2][3][5]are also used to evaluate the proposed method, while the area error is employed to measure the accuracy of segmentation. The valuation is shown in Fig. 4, and it can be seen that the sensitivity of the proposed method is about 0.97, the mean specificity is about 0.99, and the average area error (*Aerror*) is 0.0158.

Table1

Evaluation of the segmentation lung fields (Unit: pixels)

	Hu's method[4]			The proposed method		
	Sensitive	*Specificity*	*Aerror*	*Sensitive*	*Specificity*	*Aerror*
Lung1	0.918±0.071	0.998±0.001	0.029	0.978±0.011	0.997±0.001	0.019
Lung2	0.925±0.074	0.998±0.002	0.026	0.955±0.074	0.996±0.002	0.011
Lung3	0.914±0.081	0.997±0.001	0.030	0.964±0.074	0.997±0.001	0.018
Lung4	0.927±0.070	0.999s±0.001	0.027	0.947±0.050	0.995±0.001	0.010
Lung5	0.931±0.068	0.996±0.002	0.023	0.971±0.048	0.996±0.002	0.013
Lung6	0.923±0.075	0.998±0.001	0.028	0.973±0.015	0.997±0.001	0.009
Lung7	0.920±0.075	0.997±0.002	0.026	0.960±0.045	0.994±0.001	0.010
Lung8	0.912±0.087	0.996±0.003	0.035	0.952±0.077	0.996±0.002	0.021
Lung9	0.916±0.080	0.998±0.002	0.034	0.976±0.020	0.995±0.002	0.020
Lung10	*0.917±0.080*	*0.999±0.001*	*0.029*	*0.987±0.010*	*0.995±0.003*	*0.016*

A summary of the quantitative evaluation of the proposed method compared with the classical Hu's method is shown in Table 1. The sensitivity of the proposed method is about 4.99% higher on average, while the area error is 47.78% lower. And the mean specificity of both methods is 0.99. Hence, the proposed method performs better than Hu's method.

4. Discussion and conclusions

This paper described an automatic segmentation method using the thresholding combined with an anatomical information and morphological operation. Although two lung fields in the middle part of lung have narrow junction, the region located in the anatomical information can be cropped to separate the attached lung fields. If the lung field includes lobar fissures, the closing operation with a small disk can join the lobar regions. Different scans determine different indentation situation, so the disk radius of the closing operation should vary with the change of the scans accordingly. Therefore, even if the lung fields have narrow junction, lobar fissures, blood vessels, etc., the method can still get satisfactory segmentation results of lung fields by preventing the influences of the tissues using the anatomical information and morphological operation.

In summary, the proposed method employs the anatomical information, CT attenuation, shape characters and morphological operation to segment lung fields automatically. The experiment results illustrate that the method is effective for normal lungs.

5. Acknowledgments

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