A volumetric pulmonary CT segmentation method with applications in emphysema assessment

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ABSTRACT

A segmentation method is a mandatory pre-processing step in many automated or semi-automated analysis tasks such as region identification and densitometric analysis, or even for 3D visualization purposes. In this work we present a fully automated volumetric pulmonary segmentation algorithm based on intensity discrimination and morphologic procedures. Our method first identifies the trachea and primary bronchi, then the pulmonary region is identified by applying a threshold and morphologic operations. When both lungs are in contact, additional procedures are performed achieving two separated lung volumes. To evaluate the performance, we compared contours extracted from 3D lung surfaces with reference contours, using several figures of merit. Results show that the worst case generally occurs at the middle sections of high resolution CT exams, due the presence of aerial and vascular structures. Nevertheless, the average error is lower than the average error associated with radiologist inter-observer variability, which suggests that our method produces lung contours similar to those drawn by radiologists.

The information created by our segmentation algorithm is used by an identification and representation method in pulmonary emphysema that also classifies emphysema according to its severity degree. Two clinically proved thresholds are applied which identify regions with severe emphysema, and with highly severe emphysema. Based on this thresholding strategy, an application for volumetric emphysema assessment was built offering new display paradigms concerning the visualization of classification results. This framework is easily extendable to accommodate other classifiers namely those related with texture based segmentation as it is often the case with interstitial diseases.

Keywords: Medical Image Analysis, Volumetric Pulmonary Segmentation, Emphysema Assessment, Computed Tomography.

1. INTRODUCTION

Nowadays helical and multi-slice high resolution volumetric CT scanners acquire a set of slices (full exam) in a few seconds, minimizing the blur due to moving structures (respiration, cardiac beat, blood circulation, etc), being able to detect small variations in density that might correspond to physical anomalies.

Pulmonary segmentation is necessary when it is intended to study the lungs (excluding the adjacent organs), or when it is intended to extract local densitometric information. The 3D visualization methods may also require an efficient segmentation, generally included in the pre-processing task. In thoracic CT images, the contrast among low density pulmonary regions and the involving high density regions in thoracic region can be used to assist in the lung segmentation task. Traditionally an experienced radiologist delimits the pulmonary region in a CT image. More recently, computer-assisted methods are used to execute this task.

The most used 2D method for lung segmentation is based on a threshold computed from CT image histogram or on prior information, achieving a binary image, followed by binary morphologic operation and a transition detector to locate pulmonary contours. Some researchers improved this technique using smooth criterion, e.g. a rolling ball, Fiebish compared the gradient of each point to its neighbours, others used additional morphologic operations as dilation and erosion, while Taguchi used a strait line to replace abrupt changes in the contour.

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Some authors enhanced the algorithm using dynamic threshold to detect the trachea and split the lungs with user intervention or using dynamic programming, with semi-automatic smoothing of the contours. A small variant in previous “standard” algorithm, tested only in simulated CT images, corresponds to dividing the CT image in 4 sub-images exploring the correspondence among peaks in histogram with organs in CT image, followed by some image processing, as described in the previous paragraph, for each image separately.

A different approach to detect the pulmonary contours is using an active contours method, where the user manually defines some points near lung contours (seed points). The algorithm will tend to converge to lung frontier, where it achieves an equilibrium between internal energy (elastic energy of the contour) and the external energy (proportional to physical characteristics of CT image, as gradient, edge detector, pressure, etc).

In tri dimensional pulmonary segmentation there are few works published. Brown defines an anatomic model from a database with a priori information of organs to segment, as the expected volume, shape, position, and Hounsfield range values; then extracts voxels regions from CT exam, identifying the organ or structure using a comparison with a model with help of figure of merit proportional to the probability of the region of interest belong to an organ. For the separation of the lungs, identifies the 3D region were the lungs contact occurs, followed by the application of 2D segmentation method for detection of the best path based on gray level intensity.

In another work, Hu starts with the segmentation of the pulmonary volume using a threshold proportional to average of voxels gray levels that belong to thoracic region and to the average of voxel gray levels that are outside thoracic region. Automatically identifies trachea, locating the region with air in the first sections of CT exam and uses this information to detect trachea in following sections. The lung separation is done in 2D, using morphologic operations (erosion and dilation), followed by the searching of pulmonary contour using the location of highest gray levels in region of interest. Finally, the border in the mediastinic region is smoothed using erosion and dilation morphologic operations.

In this work, our objective was the development of a three dimensional pulmonary segmentation method, using information from adjacent slices, identifying the regions of interest and performing the segmentation simultaneously in all CT exams. Some innovator aspects of our 3D pulmonary segmentation method are the using of a constant threshold, reducing the number of mathematic operations and achieving more realistic pulmonary contours, allowing to overcome the difficult related with partial volume effect; other aspect is the better performance in trachea and bronchi segmentation, as well as the lung separation when they are visually merged. Our pulmonary segmentation method is able to detect all visual contact zones, even when exist multiple contact regions between left and right lungs, in the same slice or in different slices.

We start by describing the 3D lung segmentation method followed by its performance analysis based on figures of merit computed using reference contours. Finally, as an application example, we describe a method for automatic identification and classification of pulmonary emphysema.

2. 3D LUNG SEGMENTATION

The pulmonary tissue displayed on a thoracic CT image is far from corresponding to one region. Any segmentation task must have in consideration the coexistence, in the same section, of different densities, related with the vascular regions, trachea, bronchi and alveoli. The visual overlapping of the pulmonary regions can still complicate the task of segmentation.

Despite the presence of several structures, it is observed that, in most cases, the densities of the pulmonary regions are in the interval [-1000HU, -200HU]. This is valuable prior known information, which allows a discrimination of the densities in the Hounsfield scale, corresponding to the first step in the segmentation of the lungs.

Our 3D pulmonary segmentation method, as shown in figure 1, in a first step, locates the trachea in the first slice and identifies its continuity through adjacent slices, producing a volume corresponding to trachea and bronchi.
In a second step, the pulmonary region is identified by applying a threshold followed by morphologic operations (erosion, dilation, cleaning) and removing of aerial structures identified in first step. When the procedure described in previous step isn’t sufficient to isolate each lung, an additional procedure is executed to split the lungs, achieving always two pulmonary volumes: left and right lungs separated.

Figure 1– Flux diagram of 3D pulmonary segmentation method.

2.1 TRACHEA IDENTIFICATION

In a thoracic CT exam, the trachea occurs in the firsts slices, splitting in bronchi at the carina level. The most practical way to locate the trachea is to process the first slice, where the trachea always exists, then follow its continuity through adjacent slices.

To identify the trachea region (with air) in first slice, a threshold of -900HU is applied producing a binary image. To attenuate noise in the binary image, a morphologic dilation is performed; this operation also includes the trachea border in the binary image (see figure 2).

Then, it is located the large region that exist in the center of the image (in a pre-defined region). When two or more regions exist in the center of the image and have areas with similar values (might be the trachea and some pulmonary region, since pulmonary areas in first slices and trachea area may have similar value), it is selected the region which has horizontal coordinate from mass center more near the center of the image. Then, the region candidate to trachea is validated if its area is not too small (it might be another aerial structure) nor to large (it might be a lung or part of a
(lung). The minimal and maximum values were previously defined by inspecting several CT exams where the trachea was observed. After being identified in first section, its continuity is analyzed in the following slices, exploring its longitudinal continuity.

When the trachea splits into bronchi, the corresponding region in the image goes from one binary region to two binary regions in the next image, one for each bronchus. This procedure is repeated for all slices until the trachea or the bronchi correspond to very small areas, usually placed inside pulmonary region, ending the identification of trachea and bronchi.

2.2 PULMONARY REGION IDENTIFICATION

To identify the lungs boundaries in a CT exam, a threshold is applied followed by morphologic operations to remove extra-toracic regions. In order to smooth the irregularities in lung border, due to vascular and aerial structures in mediastinic region, dilation and erosion morphologic operations are used.

2.2.1 THRESHOLD

Frequently, the pulmonary segmentation methods, in a first step, compute the image histogram and locate the local minimum near -550HU, that is, the local minimum that exist between the two maximums of histogram (see figure 3) and use it as a threshold for the separation between pulmonary regions (left maximum) and the bone and muscle (right maximum). The value of this threshold is adaptive in the sense that varies from CT exam to CT exam.

In the method that we described in this section, a different approach is used: we use a constant threshold, independently of the CT exam to be processed, allowing to overcome obstacles related with a segmentation with a variable threshold, in regions where the partial volume effect occurs.
The threshold value (minimum in histogram, near -550HU) was computed experimentally, for each of 19 CT high resolution or volumetric exams shown in table 1. The average value computed from these 19 CT exams (shown in table 1) is -403HU, a value similar to -405HU computed by Leader 16, that processed about one hundred CT exams.

Table 1 – Properties of CT exams and computed thresholds.

<table>
<thead>
<tr>
<th>CT exam (name)</th>
<th>Number of slices</th>
<th>Slice Thickness (mm)</th>
<th>Threshold (HU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 1</td>
<td>22</td>
<td>1</td>
<td>-454</td>
</tr>
<tr>
<td>B 1</td>
<td>26</td>
<td>1</td>
<td>-526</td>
</tr>
<tr>
<td>C 8</td>
<td>31</td>
<td>8</td>
<td>-398</td>
</tr>
<tr>
<td>D 1</td>
<td>24</td>
<td>1</td>
<td>-384</td>
</tr>
<tr>
<td>E 5</td>
<td>43</td>
<td>5</td>
<td>-562</td>
</tr>
<tr>
<td>F 1</td>
<td>24</td>
<td>1</td>
<td>-449</td>
</tr>
<tr>
<td>G 1</td>
<td>21</td>
<td>1</td>
<td>-351</td>
</tr>
<tr>
<td>H 8</td>
<td>26</td>
<td>8</td>
<td>-305</td>
</tr>
<tr>
<td>I 8</td>
<td>25</td>
<td>8</td>
<td>-352</td>
</tr>
<tr>
<td>J 5</td>
<td>41</td>
<td>5</td>
<td>-428</td>
</tr>
<tr>
<td>L 1</td>
<td>18</td>
<td>1</td>
<td>-274</td>
</tr>
<tr>
<td>M 1</td>
<td>22</td>
<td>1</td>
<td>-458</td>
</tr>
<tr>
<td>N 5</td>
<td>42</td>
<td>5</td>
<td>-412</td>
</tr>
<tr>
<td>O 1</td>
<td>21</td>
<td>1</td>
<td>-492</td>
</tr>
<tr>
<td>P 8</td>
<td>23</td>
<td>8</td>
<td>-364</td>
</tr>
<tr>
<td>Q 1</td>
<td>22</td>
<td>1</td>
<td>-272</td>
</tr>
<tr>
<td>R 1</td>
<td>23</td>
<td>1</td>
<td>-421</td>
</tr>
<tr>
<td>S 8</td>
<td>28</td>
<td>8</td>
<td>-346</td>
</tr>
<tr>
<td>T 1</td>
<td>24</td>
<td>1</td>
<td>-411</td>
</tr>
</tbody>
</table>

Nevertheless, the threshold values shown in table 1 have a considerable dispersion [-562HU to -272HU] and might negatively influence the pulmonary segmentation, as it occurs in CT section of figure 4. This figure corresponds to a slice image from a volumetric CT exam, and we see that the major difference between contours drawn by a radiologist (considered as reference) and the computed contours (produced by 3D pulmonary segmentation method), using a variable threshold (variable with the CT exam), is due to partial volume effect.

![Figure 4](image)

Figure 4 – Pulmonary contours that correspond to worst case pulmonary segmentation with variable threshold.

Specially in images where the partial volume effect occurs, when the segmentation is done with a variable threshold, if it is too far away from -550HU, an incorrect pulmonary segmentation might occur.

So, and as the lungs correspond to Hounsfield values in range -950HU to -550HU 17, the 3D pulmonary segmentation method here described uses a threshold of -550HU, producing a binary volume which includes pulmonary regions and others outside-body regions (e.g., air).
2.2.2 PULMONARY LOCALIZATION AND BORDER SMOOTHING

After trachea identification, the next step is the removing of outside-body regions, using a morphologic fill operation starting in a vertex of the binary volume previously computed. Then, the trachea and the bronchi are excluded and the final binary volume produced corresponds to pulmonary regions.

The two biggest regions are identified and their volume values computed. If these values have the same magnitude, then correspond to two lungs; else both lungs are in contact and this method identified two lungs as a large 3D region, it is then necessary to locate the separation region.

2.2.3 LUNGS SEPARATION

When it is necessary to identify the lungs separation surface, the starting point is the binary volume (BIN_VOL) that corresponds to the 3D pulmonary region. To obtain the regions that correspond to left and right lungs, several operations are performed, as shown in pseudo-code 1.

The first step is the identification of the region of interest (LUNG_BINARY) with size of \([\frac{d}{2}..\frac{d}{2}; \frac{d}{2}..\frac{d}{2}; 1..n]\) voxels centered in binary volume (BIN_VOL), where \(d\) is the axial size of the image (usually 512 pixels) and \(n\) is the number of slices. Then, several erosions are performed until two regions with similar volume (same magnitude) are obtained, these two regions (SUB_VOL_LEFT and SUB_VOL_RIGHT), are classified as left and right pulmonary sub-regions using as reference their mass center. For this morphologic operations it is used a structuring element \([3\times3\times3]\) with all its elements as “0” except the central voxel and their first neighbours (with face to face continuity) in axial plane, which have value “1”, once that CT exams, usually have a high axial resolution (typically 512 pixels) and a low longitudinal resolution (typically much less than one hundred).

Then, the volumes SUB_VOL_LEFT and SUB_VOL_RIGHT are iteratively dilated, using the same structuring element until the group of these two sub-volumes (SUB_VOL_LEFT \(\cup\) SUB_VOL_RIGHT) includes the lungs that we intend to separate (LUNG_BINARY). The intersection of the three computed regions (SUB_VOL_LEFT \(\cap\) SUB_VOL_RIGHT \(\cap\) LUNG_BINARY) corresponds to 3D regions (we call VOL_CONTACT to each one of these regions) where the contact zones between the left and right lungs occur.

Pseudo-code 1 – Lung Separation

```plaintext
// Input: binary volume (BIN_VOL) with dimensions \([1..d, 1..d, 1..n]\)
LUNG_BINARY = BIN_VOL(\(\frac{d}{2}..\frac{d}{2}, \frac{d}{2}..\frac{d}{2}, 1..n\)) // select the region of interest
Successive erosions in LUNG_BINARY until occur 2 volumes with similar volume value are obtained; correspond to SUB_VOL_LEFT and SUB_VOL_RIGHT
Dilation of SUB_VOL_LEFT and SUB_VOL_RIGHT until SUB_VOL_LEFT \(\cup\) SUB_VOL_RIGHT are inside of LUNG_BINARY
VOL_CONTACT = SUB_VOL_LEFT \(\cap\) SUB_VOL_RIGHT \(\cap\) LUNG_BINARY // binary volume which includes the lung contact regions
Identification of each region in VOL_CONTACT
If each region of VOL_CONTACT includes both 3D regions (SEP_LEFT and SEP_RIGHT) and each one of these regions is in contact with regions that correspond to the left and right lungs, respectively, then:
   SUB_VOL_LEFT = SUB_VOL_LEFT \(\cup\) SEP_LEFT
   SUB_VOL_RIGHT = SUB_VOL_RIGHT \(\cup\) SEP_RIGHT
   SUB_VOL_LEFT = SUB_VOL_LEFT \(\cap\) NOT (SEP_RIGHT)
   SUB_VOL_RIGHT = SUB_VOL_RIGHT \(\cap\) NOT (SEP_LEFT)
else is performed a 2D pulmonary separation: for each VOL_CONTACT it is located the region of interest, applied thresholds and morphologic operations iteratively until two binary images are produced.13
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Each one of these regions (VOL_CONTACT) is analyzed. If VOL_CONTACT is two independent regions (SEP_LEFT and SEP_RIGHT), each one in contact with left and right lungs, respectively, then the lungs are already separated (for this VOL_CONTACT), and these regions (SEP_LEFT and SEP_RIGHT) are included in regions SUB_VOL_LEFT and SUB_VOL_RIGHT, respectively, and removed from SUB_VOL_RIGHT e SUB_VOL_LEFT, respectively, else thresholds and morphologic operations are applied (as described in 13) until two binary images are produced.
This method proved to be sufficient to separate lungs in CT exams, even when the contact region occurs in multiple regions.

![Image of two lungs with multiple contact regions.](image)

Figure 5 – Two lungs with multiple contact regions.

2.3 RESULTS

During the development period, this method was trained with one HRCT exam (slices of 1mm thickness and distance between slices of 8mm) and with one volumetric CT exam (adjacent slices, with 8mm thickness).

To test this method, 19 CT exams were segmented, including high resolution and volumetric CT exams. In table 1 it is shown the number of slices of each CT exam and the thickness of each slice, where HRCT exams have 1mm thickness and volumetric CT exams have 5mm or 8mm thickness.

3. EVALUATION

The segmentation method was applied in 19 CT exams, which totalize several hundred slices, not being admissible to ask radiologists to draw lung contours for these hundred slices. But in a 2D pulmonary segmentation method was developed and validated for a set of 60 contours, as a pulmonary boundary detector equivalent to radiologists. The contours produced by this detector were used as reference contours. From several hundred reference contours produced, was selected about ten images in which contours correspond to abnormal segmentation, and those were shown to a thoracic experiment radiologist that analyzed them and classified the reference contour as “acceptable” or better. To classify the similarity between contours, we used the Pratt figure of merit, the mean error, and the percentage of points with error higher than 5 pixels, as described in.

3.1 PERFORMANCE OF THE 3D SEGMENTATION METHOD

To evaluate the performance of our segmentation method, we processed several CT exams (shown in table 1) and, as the number of slices changes from CT exam to CT exam, we defined the first and last slices in a CT exam corresponding to 0% and 100% longitudinal positions, respectively, and computed the 18 slices that correspond to longitudinal positions from 5% to 95% with a step of 5%, obtaining a group of 20 slices almost uniformly spaced, selected from a CT exam and representative of this CT exam. After applying the 3D pulmonary segmentation method to CT exam, these 20 slices are identified and the lung contours extracted (20 slices × 2 contours → 40 contours by CT exam), and compared with correspondent reference contours. Then, the figures of merit were computed. In box-plot of figure 6 is represented one of these figures of merit: mean error.

Observing the mean error figure of merit, we see that almost all values are lower than 0.5 pixels, also the median values are near zero, so the contours produced by our 3D pulmonary segmentation method when compared with the reference, have a mean error almost null (about zero pixels). This small difference suggests that the 3D pulmonary segmentation method produces contours similar to contours produced by radiologists, once that (as referred in) the mean error associated with contours drawn by radiologists is higher than 1 pixel.
In figure 6, despite the outliers, the number of these points belonging to each CT exam is very small when compared with total number of points in corresponding CT exam (40 points, once that each contour corresponds to a figure of merit value, and each exam has 40 contours).

![Figure 6 – Box-plot corresponding to mean error figure of merit, for each CT exam processed.](image)

To the next analysis, we recall that last digit in CT exam name corresponds to the thickness, names ending in “1” are high resolution exams and names ending in “5” or “8” are volumetric exams (see table 1). Observing the range values of second and third quartet (rectangular box for each CT exam, represented in figure 6) and the position of medians, we see that high resolution exams are less similar to reference than volumetric exams; also that the high resolution CT exams have outliers with higher values due to the presence of vascular and aerial structures (although of small size) that influence negatively the segmentation in slices from high resolution CT exam; on the other hand, in volumetric CT exams these structures are masked by mean values of lung tissues in those regions.

We also used Pratt figure of merit and the results obtained are coherent with previously observations, i.e., the contours produced by 3D pulmonary segmentation method in volumetric CT exams are more similar to reference than the results obtained from high resolution exams.

3.2 LONGITUDINAL VARIATION

In this section, we analyze the similarity between the contours produced by 3D pulmonary segmentation method and the reference contours, through longitudinal axis, from top level (apex) to lower level (basal).

Figure 7 shows the worst case values for each longitudinal position, for high resolution and also for volumetric exams, computed by figure of merit percentage of points with error higher that 5 pixels. We observe higher errors for longitudinal positions between 40\% and 65\%. This variation suggests that 3D pulmonary segmentation method is more similar to the reference in first and last longitudinal levels, since in positions near 50\% (place where the trachea divides in bronchi, and where exist large vascular structures) it is more difficult to detect the correct pulmonary contours.

4. AUTOMATIC IDENTIFICATION AND CLASSIFICATION OF PULMONARY EMPHYSEMAS

The linear attenuation coefficient values for the normal lungs are higher than -875HU. The linear attenuation coefficient values for the emphysematous lung are lower than -875HU and the corresponding voxels (from CT exam) might be identified using an appropriate threshold. In recent works, Kishi observed the existence of lung cancer in 2\% to 5\% of patients with lung emphysema, being necessary the distinction of regions with lung emphysema and the non-affected lung tissue.
To identify emphysematous regions, Bankier 22 used pulmoCT software (from Siemens) to obtain lung contours and to identify the regions that belong to an intensity range, using the -950UH value as a threshold. Kishi 20, in a work to identify lung cancer, used Advantage Windows 3D software (from GE), having excluded the trachea and bronchi, selectively; for threshold used -900UH. Gierada 23 used pulmoCT software (from Siemens) to segment semi-automatically the lungs and to do densitometric measures in order to classify the emphysema; he used several threshold, -900UH and -960UH. Park 24 used Advantage Windows 3D software (from GE) to segment lungs, removing trachea and bronchi; computed the histogram from CT exam and applied -900UH, -910UH and -950UH thresholds, classified the 2D images from CT exams sections with 0, 1, 2, 3 or 4 according to percentage of 2D lung region with emphysema (0 = no emphysema, 1 = from 1% to 25% of lung tissue with emphysema, 2 = from 26% to 50% of lung tissue with emphysema, etc). Becker 21 compared the pulmonary volumes before and after pulmonary capacity reduction surgery; developed a semi-automatic algorithm in which the user defines a pixel in the region with emphysema and the algorithm expands the region to all neighbour pixels with same range intensity (region growing), trachea and bronchi are manually removed.

4.1 METHOD DESCRIPTION

With the purpose of identify and quantify the extension of pulmonary regions with emphysema, we developed this method that also classifies the pulmonary emphysema according to its probability of occur. To do so, some criterions proposed by several authors are used. It is defined a region with high probability of being emphysema when the linear attenuation coefficients are lower than -900UH (emphysematous region A, in figure 8) 21,24,23,20, and a region with very high probability of being emphysema when the same coefficients are lower than -950UH (emphysematous region B, in figure 8) 22,24.
In order to identify the emphysematous regions, as a pre-processing step, the pulmonary segmentation is performed using the method described in section 2. Then, two thresholds are applied that correspond to two probability levels of occurring regions with emphysema.

For each slice the areas of A and B emphysematous regions are computed. This information is visualized as a chart, with percentage values in relation to pulmonary area for that slice (as shown in figure 11). To better observe the position of emphysematous regions in the lungs, tri dimensional images with the pulmonary region, the trachea and bronchi, and also the regions with emphysema are represented.

To allow a traditional view and also a more accurate image, bi dimensional images are produced for each slice of CT exam in which the two types of emphysematous regions are delimited with distinct colors. It is also produced the CT exam topogram in which the emphysematous regions are also delimited.

4.2 RESULTS

The identification, quantification and classification method for pulmonary emphysemas produces several types of results, from charts to bi dimensional and tri dimensional images.

![Image Produced by the Over Position of Lungs, Trachea, Bronchi and Emphysema Regions.](image9.png)

Figure 9 – Image produced by the over position of lungs, trachea, bronchi and emphysema regions.

The image show in figure 9 allows to see the lungs, trachea, bronchi and also the regions with emphysema. With this type of image, it is possible to compare visually the lung volumes and the emphysematous pulmonary volumes.

![CT Exam Section with A and B Emphysematous Regions.](image10.png)

Figure 10 – CT exam section with A and B emphysematous regions.

One of the bi dimensional image produced, corresponds to section image (selected by the user) in which the A and B emphysematous regions are delimited with different colors (see figure 10).

Finally, but not less important, two charts that represent the percentage of pulmonary region with emphysema in each slice are produced. For example, figure 11 shows that 11% of the area of slice 17 corresponds to emphysematous region type A; on the other hand, 8% of the area of that slice corresponds to emphysematous region type B.
4.3 DISCUSSION

This method was applied in 19 CT exams, that include high resolution and volumetric CT exams (shown briefly in table 1), 2/3 of which have regions with pulmonary emphysema.

The proposed method is more complete than most methods previously described, due to the variety of representation (also allows a qualitative analysis of the volumes), due to the localization of regions where the emphysema occurs with corresponding representation in respective slice of CT exam, and also due to quantitatively analysis of regions with different probability levels of being emphysema.

This application may also be applied to other type of diseases where classification is achieved by direct or indirect measure of the linear attenuation coefficients.

5. CONCLUSIONS

In this work we presented a 3D pulmonary segmentation method that used a threshold with morphologic operations, to produce a pulmonary binary volume, in which the aerial structures (trachea and bronchi) are identified. When both lungs are in contact, additional procedures are executed to locate the lung separation surface. The irregularities due to vascular and aerial structures that occur mainly in mediastinic region are attenuated using smoothing morphologic operations.

The performance of 3D pulmonary segmentation method was compared with a reference. Several figures of merit were used and suggest that our method produces lung contours similar to contours drawn by radiologists. Analyzing the longitudinal variation of mean error figure of merit, we observed that the more similarities occur in firsts and lasts slices from CT exam. In the mediastinic region, the pulmonary segmentation method on high resolution CT exams produces results less similar to the reference than in volumetric CT exams, since in this region a large vascular structures exists (when compared to the majority of vascular structures in the lungs) that became partially masked in volumetric exams.

The results of 3D pulmonary segmentation method were evaluated qualitatively and quantitatively and suggest that the lung volumes produced by this segmentation method are equivalent to lung contours drawn by radiologists.

We proposed an identification, quantification and classification method for pulmonary emphysemas, as an application example of pulmonary segmentation. In a first step, uses the 3D pulmonary segmentation method developed to identify the pulmonary regions. Then, to identify emphysematous regions, applies two thresholds and quantifies the regions with two types of emphysema. The results are presented as 3D pulmonary images, slice images in which emphysematous regions are delimited, and also charts where the percentage of area with emphysema, for each slice, is observed.
6. REFERENCES