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3d Lung Vessel Segmentation In Computed Tomography Angiography Images

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Abstract: *In this paper, a novel lung vessel segmentation method is introduced. In this method, some Reference Points (RPs) were determined by making use of the properties of unchangeable anatomical structure. Due to these RPs, truncus, left-right pulmonary artery, lobar segment vessels have been segmented and subsegment vessels have been detected by looking at the differences of intensities in lung region. If there is pulmonary emboli (PE), heart disease, or abnormal tissues, vessel structure doesn't regularly continue and decreases the sensitivity of segmentation. Using RPs, vessel structure becomes more definite and sensitivity of the segmentation increases. CTA images belonging 30 patients including different disease are examined and 95% of sensitivity is obtained. The performance of the method for lung vessel segmentation is found to be quite well for radiologists and it gives enough results to the surgeries medically.*
Keywords: *Computed Tomography Angiography (CTA), Lung Segmentation, Lung Vessel Segmentation, Computer Aided Detection (CAD)*

1. Introduction

Vessel segmentation is a fundamental for a variety of applications, for instance Pulmonary Embolism (PE) detection and visualization [1-5], lung nodule detection [6,7], interstitial lung disease (ILD) [8–10], emphysema [11,12], assistance in bronchoscopic navigation, lobe segmentation, and surgical planning. Moreover, the vessel segmentation provides an equipment to understand the relation between vessels and diseases.

Typical pulmonary vessel segmentation was widely investigated in the past. Kiraly et al. segmented the lung vessels in contrast enhanced CT data by first applying a threshold operation to the lung areas [13]. Buelow et. al. used fast marching techniques for segmentation of lung vessels [14]. Yuan et al. determined the inner and outer boundaries of the blood vessel wall in MR images [15], Poli et al. defined a set of linear filters, whose kernels are a combination of Gaussian distributions [16]. Zhou et al. pulmonary vessel tree segmented by a threshold based region growing method from CT images without any contrast enhancement [17]. Masutani et al. proposed a propagation scheme based on bounded space mathematical morphology [18]. Zhang et al. propose to use level set methods to extract pulmonary vessels from CT data. In their framework, they combine edge and region-based speed terms to model the front propagation in a multiscale space [19]. Agam et al. and Shikata et al. used a filter-based method for lung vessel segmentation [20, 21].

In this paper, we propose a new CAD system for automatic segmentation of lung vessel in CTA images. Lung vessel segmentation is differently carried out from previous works. Some Reference Points (RP) were detected by making use of the properties of unchangeable anatomical structure, in order to use at vessel segmentation besides some methods which were known. Due to these RPs, truncus, left-right pulmonary artery, lobar segment vessels have been segmented and subsegment vessels have been detected by looking at the differences of intensities in lung region. Then, lung vessel tree has been detected by connecting all of the

vessels. The results at the end of these processes have been analyzed by the performance measures which are used in medical image evaluation.

As a result the sensitivity of the method was determined as 95% at a specificity level of 98%. We used the data sets that have PE, heart disease, and abnormal tissues because of lung disease except PE. When these conditions are considered, the performance of the method for lung vessel segmentation at this paper is better than the ones in literature and it gives rather enough results to the surgeries medically.

2. Materials and Methods

In this work, data was collected from Dr. Siyami Ersek thoracic and cardiovascular surgery training and research hospital. All pulmonary computed tomography angiography exams performed with 16 detectors CT (Somatom Sensation 16, Siemens, AG, Erlanger, Germany) equipment. Patients were informed about the examination and also for breath holding. Imaging performed with Bolus tracking program. After scenogram, single slice is taken at the level of pulmonary truncus. A bolus tracking is placed at pulmonary truncus and trigger is adjusted to 100 HU (Hounsfield Unit). 70ml nonionic contrast agent at the rate of 4mL/sec with an automated syringe (Optistat Contrast Delivery System, Liebel-Flarsheim, USA) is used. When opacification is reached at the pre-adjusted level exam performed from the supraclavicular region to the diaphragms.

Contrast injection performed via 18-20G intra venous cannula that was placed at antecubital vein. Scanning parameters were 120 kV, 80- 120 mA, slice thickness 1 mm, pitch 1.0-1.2. Images reconstructed with 1mm and 5mm thickness, and evaluated at mediastinal window (WW 300, WL 50) with advanced workstation (Wizard, Siemens, AG, Erlanger, Germany) in coronal sagittal and axial planes. Oblique plans used if needed. Each exam consists of 400-500 images with 512x512 resolutions. Data sets belonging to 30 patients were used. 13 of them are female and 17 of them are male. Ages of females change between 31 with 80 and ages of males change between 40 with 79

In CTA images, to being able to segmented of lung vessels properly is quite important to diagnosis some disease. In this paper, a new method was performed in order to lung vessel tree could be correctly segmented. Firstly, lung segmentation was achieved and Mediastinum Region (MR) was detected. Then the vessels which have inside of the MR and inside of the Lung Region (LR) were separately segmented. Lastly, lung vessel tree has been detected by connecting all of the vessels. The detailed follow chart of this method is shown in Fig. 1.

2.1. Lung Segmentation and Mediastinum Region Detection

To detect Lung region, firstly each image has been threshold using -300 HU as the level of threshold. Each of components in the image have labeled with "Connected Component Labeling algorithm" (CCL) Then, looking at the size of each labeled piece, components, whose pixel numbers are under 1000, were removed from the image. Lastly, regions which inside of patient's body were determined as right and left lung region. In Fig. 2a first patient's original image, in Fig. 2b 2D segmented lung, in Fig. 2c 3D segmented lung are shown.

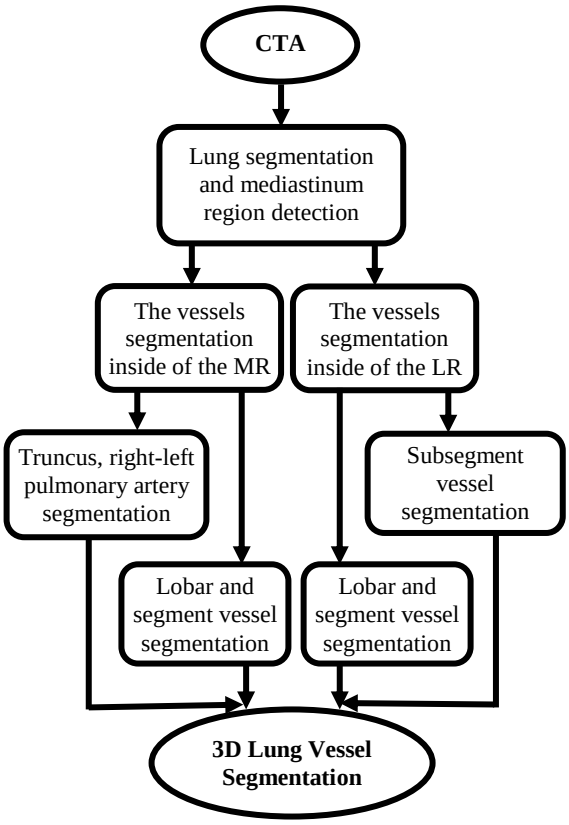
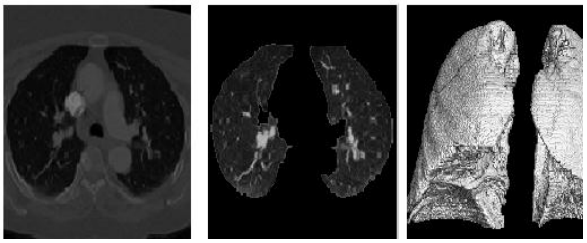


Figure 1. Flow chart of the method



a) b) c)

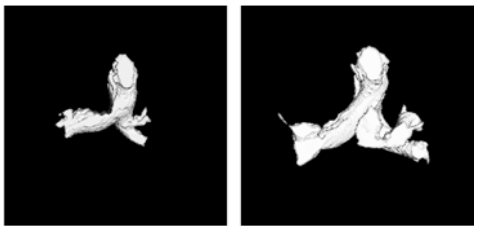
Figure 2 a) Original 2D CTA image, b)2D segmented lung, c)3D segmented lung

After lung segmentation, region of between right-left lungs has been determined as MR

2.2. The Vessels Segmentation Inside of Mediastinum Region

2.2.1. Truncus, Right-Left Pulmonary Artery Segmentation

To segment truncus, right-left pulmonary artery, firstly, components which are outside of the MR were removed from the 2D images. Then each image has been threshold using 300 HU < Image < 500 HU as the level of threshold. The images are labeled by CCL as 3D and the components have been removed except the one which has the biggest size from the image. Last component is truncus, right-left pulmonary artery. In Fig. 3a-3b first and second patient's truncus, right-left pulmonary arteries are shown as 3D.

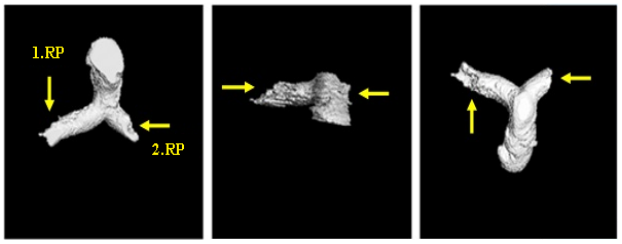


a) b)

Figure 3 a) 3D First patient's truncus, right-left pulmonary artery, b) 3D Second patient's truncus, right-left pulmonary artery

2.2.2 Lobar and Segment Vessel Segmentation Inside of the Mediastinum Region

If there is no PE in lung vessels, the vessels properly continue from truncus forward to left-right pulmonary artery. However, if there is PE in lungs, vessel structure doesn't regularly continue due to the low-threshold value of the PE. The first spoiling points of the vessel structure at left and right have been detected as Reference Points (RP). In Fig. 4, third patient's truncus, right-left pulmonary artery, which are in different position, are shown.

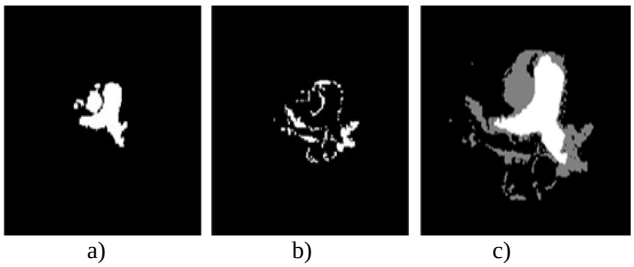


a) b) c)

Figure 4 a)b)c) Third patient's truncus, right-left pulmonary artery which seen different position

First points which ruin vessel structure are shown with arrows in Fig 4. First spoiling point at right pulmonary artery is determined as 1st RP. First spoiling point at left pulmonary artery is determined as 2nd RP. To detect RPs, firstly, voxels of each 3D cross section are examined. The voxel number whose vessel structure doesn't continue regularly is less than whose vessel structure continues regularly. First points of voxel numbers which decrease are determined as RPs.

Then, to use in segmentation, MR thresholding is carried out. Firstly, components which are outside of the MR were removed from the images. Components are labeled by CCL as 2D, and ones whose voxel numbers are under 1000 were removed from the images which were obtained for vessel. Then each image has been threshold using 150 HU < Image < 500 HU for vessel (Fig 5a), and 1 HU < Image < 150 HU for PE (Fig 5b) as the level of threshold. Images of truncus, right-left pulmonary artery which were acquired from Section 2.2.1 with the two images which were obtained for vessel and for PE from this section were gathered (Fig 5c).

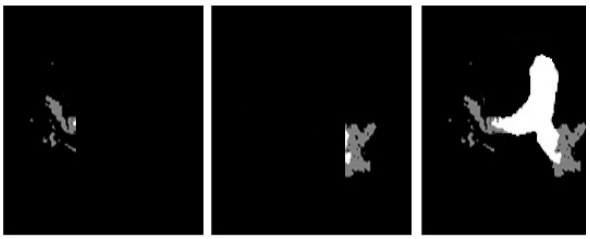


a) b) c)

Figure 5 a) MR which threshold for vessel, b) MR which threshold for PE, c) MR which threshold for vessel and PE

After these processes, Lobar and segment vessel segmentation inside of the mediastinum region are carried out. To segment right side, left side of 1st RP is taken, right side of 1st RP is removed from image which seen at Fig. 5c (Fig 6a). To segment left side, right side of 2nd RP is taken, left side of 2nd RP is removed from image which seen at Fig. 5c

(Fig 6b). Lastly left and right vessels are gathered with truncus, right-left pulmonary artery (Fig. 6c). So, Lobar and segment vessel segmentation inside of the mediastinum region is carried out.



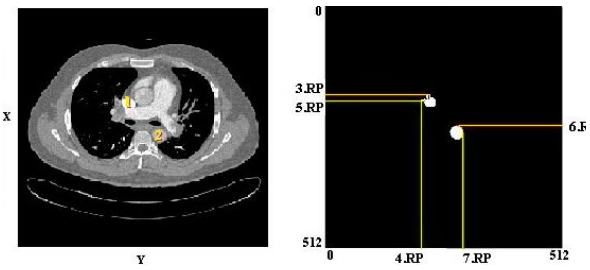
a) b) c)

Figure 6 a) Right lobar segment vessels inside of the mediastinum region, b) Left lobar segment vessels inside of the mediastinum region, c) Total lobar segment vessels inside of the mediastinum region

2.3. The Vessels Segmentation Inside of Lung Region

2.3.1 Detection of Reference Point

To detect vessels which continue towards of lung region from end of MR were determined some RP at right and left. In 2D CTA images, vessels which continue towards right lung region go to the right side of Superior Vena Cava (SVC) which shown with number 1 in Fig. 7a. Vessels which continue towards left lung region go to the left side of Descending Aorta (DesA) which shown with number 2 in Fig. 7a. Therefore, SVC and DesA are detected to determine RPs. Then Xmin of SVC in each of 2D image has been called 3rd RP and Ymin as 4th RP. The middle point in X dimension of SVC has been defined as 5th RP for each of 2D image (Fig. 7b). In the same way, Xmin of DesA has been called 6th RP and Ymax as 7th RP in each of 2D image (Fig. 7b).



b)

Figure 7 a) Original images, b) Images which determined RPs

While 2D CTA images are going on towards image of heart, heart grows up towards the left lung. During heart expanding, lobar segment vessels are seen under the expanding point which is shown with arrow in Fig. 8. Therefore 8 thRP is determined from the expanding points (Fig. 8). To detect expanding point, firstly, the region between the 3rd RP and 7th RP of lung has been taken and replaced to a new image. Secondly, Ymin of the new image and Xmax of the cross section in Ymin have been detected. Here, Xmax is called 8th RP. This method has been applied to all of the images from the image beginning of truncus to the image end of the lobar segment vessels and detected reference points have been loaded to a vector with the image numbers.

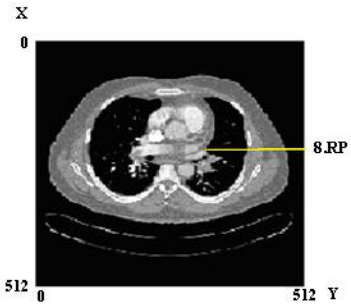


Figure 8. Image which determined 8th RP

2.3.2 Lobar and Segment Vessel Segmentation Inside of the Lung Region

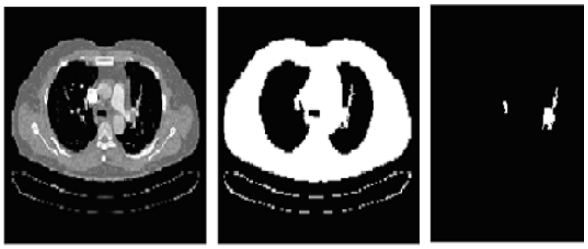
To segment, firstly, components which are outside of the MR were removed from the images. Then each image has been threshold using 1 HU < Image < 500 HU as the level of threshold. The images which are inside of the lung region can be segmented easily. Secondly, to segment the vessels of right side, left side of Ymax point of cross section of 5th RP in X dimension in right lung image is taken and right side is removed and, components which are smaller than 3th RP in X dimension are removed from image Fig. 8 as in Fig 9a. To segment the vessels of left side, region which is bigger than 7th RP and 8th RP is taken from image Fig. 8 as in Fig 9b.

a) b)

Figure 9 a) 2D lobar and segment vessel inside of the right lung region, b)2D lobar and segment vessel inside of the left lung region

2.3.3 Subsegment Vessel Segmentation

Segmentation of lobar and segment vessels from the first image, which truncus rise, to the first image, which lobar and segment vessel rise in MR, is achieved in this section. For this process, firstly each image has been threshold using Image >-300 HU as the level of threshold. Then components are labeled by CCL as 2D, and ones, whose number of voxels is under 1000, were removed from the images (Fig. 10b). Secondly, the difference of the image in Fig. 10b and the previous image are defined (Fig. 10c). Since the lobar or segment vessels haven't arisen yet in previous image, components in the difference image have been determined as lobar or segment vessels.



a) b) c)

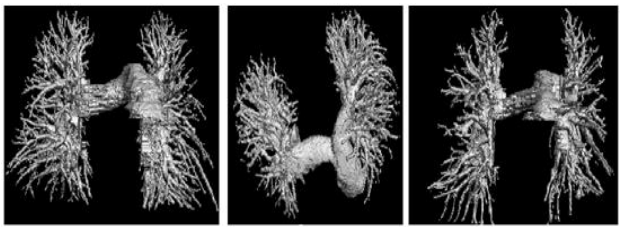
Figure 10 a) Orijinal image, b)Threshold image, c) The difference of two 2D images

Thirdly, subsegment vessels are segmented, the small components, which are in lung region, were determined as subsegment vessel. For this, the components are labeled by CCL as 2D, and ones whose number of voxels is under 100 were detected as subsegment vessel. Lastly, vessels, which are detected at the second and the third steps, are gathered (Fig. 11).

Figure 11. Subsegment and lobar segment vessels

2.4. 3D Lung Vessel Segmentation

The results in section 2.2 and 2.3 have been gathered to achieve the whole lung vessel segmentation. The last image consists of totally vessels. 3D lung vessel images, which obtained from the 2D images belong to the three patients, can be seen in Fig. 12.



a) b) c)

Figure 12 a)b)c) 3D lung vessel images belongs to three deference patients

3. Results

Segmented lung vessel trees, which belong to each patient, are reviewed by radiologists and numbers of branches belong to lung vessel trees are evaluated. The true and false branches were counted manually. Then, the number of true branches was detected as True Positive (TP), the number of missing branches was detected as False Negative (FN), the number of false components which were detected as vessel branches but not vessel branches was detected as False Positive (FP). Lastly, the number of the components which weren't detected and not vessel branches was detected as True Negative (TN). The results at the end of these processes have been analyzed by the performance measures which are used in medical image evaluation. Sensitivity was calculated by Eq. (1)

$$Sensitivity = \frac{\mathrm{TP}}{\mathrm{TP+FN}} \times 100 \quad (1)$$

Specificity was calculated by Eq. (2)

$$Specificity = \frac{\mathrm{TN}}{\mathrm{TN+FP}} \times 100 \quad (2)$$

According to the results of 30 patients, it is observed that the sensitivity changes between 80% with 95% and the 1-specificity changes between 0.01 with 0.2. The ROC graph (Receiver Operating Characteristic) formed according to the results can be seen in Fig. 13.

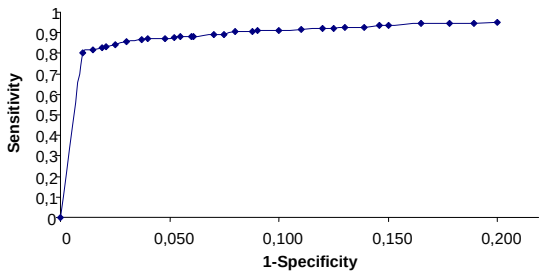


Figure 13. ROC curve belongs to 30 patients

It has been seen that the performance of the method for 3D lung vessel segmentation at this paper is quite

good and it gives enough results to the surgeries medically.

4. Conclusion

In this paper, Lung vessel segmentation is differently carried out from previous works. Data sets consist of females and males who are different ages. There are several approaches to vessel segmentation in the past studies. For instance, Agam et al. used a filter-based method for lung vessel segmentation. They made a distinction between vessels, their junctions, and nodules with the filter-based method [20]. Their goal is to increase the performance of lung nodules detection. So, their data sets are only patients who have lung nodules. Lung vessel segmentation is easy at the patients who have lung nodules, because inside of vessels are clear. Data sets of patients that have PE, heart disease or abnormal tissues because of lung disease except PE are used in this work. These diseases damage the vessel structure. So, lung vessel segmentation is quite difficult from the data sets belonging to patients that have PE. Kiraly et al. used data sets that have PE and applied a filter-based method and threshold in their work [13]. Zhou et al. and Zhang et al. used data sets that have PE and applied region growing methods to segment lung vessel tree [17,19]. Kaftan et al. applied both threshold and seed-point based methods and at the end of their works, sensitivity of the method was determined as 89% at a specificity level of 98% [5]. If there are PE, heart disease, or abnormal tissues, vessel structure doesn't regularly continue. In this case, region growing method filter-based method and threshold is not enough to make segmentation. So the performances of the methods in previous works are lower.

In this work, to segment, a novel method is presented. Some Reference Points (RP) were detected by making use of the properties of unchangeable anatomical structure, in order to use in vessel segmentation besides some methods which were known. Due to these RPs, truncus, left-right pulmonary artery, lobar segment vessels have been segmented and subsegment vessels have been detected by looking at the differences of intensities in lung region. Then, lung vessel tree has been detected by connecting all of the vessels. 3D Lung vessel segmentation is applied to 30 patients. As a result the sensitivity of the method was determined as 95% at a specificity level of %98. Rate of sensitivity is bigger than the previous works. Data sets that have PE, heart disease, and abnormal tissues because of lung disease except PE are used. When these conditions are considered, the performance of the method for lung vessel segmentation at this paper is better than the ones in the literature and it gives rather enough results to the surgeries medically. This work contributes to diagnose the lung vessel diseases. Especially, PEs which are inside vessel can be easily diagnosed thanks to lung vessel segmentation which are developed in this paper.

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