A method for automated extraction of aorta and pulmonary artery in the mediastinum using medial line models from 3D chest X-ray CT images without contrast materials

Takayuki Kitasaka
Graduate School of Engineering,
Nagoya University, Nagoya 464-8603, Japan
kitasaka@toriwaki.nuie.nagoya-u.ac.jp
Tel: +81-52-789-3310
Fax: +81-52-789-3807

Kensaku Mori
Image Guidance Laboratories,
Department of Neurosurgery,
Standford University, USA.
mori@cse.nagoya-u.ac.jp

Jun-ichi Hasegawa
School of Computer and Cognitive Sciences,
Chukyo University, Toyota 470-0393, Japan
hasegawa@sccs.chukyo-u.ac.jp

Jun-ichiro Toriwaki
Graduate School of Engineering,
Nagoya University, Nagoya 464-8603, Japan
toriwaki@nuie.nagoya-u.ac.jp

Abstract

This paper proposes a new method of automated extraction of aorta and pulmonary artery (PA) areas in the mediastinum from uncontrasted 3D chest X-ray CT images. The proposed method does not extract contours of these blood vessels directly, but extracts the medial line of each vessel and recovers each vessel area. First, the process performs edge detection based on the local standard deviation to get edge areas of vessels. Second, the Euclidean distance transformation is applied for non-edge areas and the likelihood image of the center of vessels is obtained. Medial line models are deformed basing upon the likelihood image so as to be fit to the center of each artery. The aorta and the PA areas are obtained by applying the reverse distance transformation to medial lines extracted above. We applied the proposed method to seven cases of uncontrasted 3D chest X-ray CT images. The experimental results showed that the aorta and the PA areas could be extracted satisfactorily.

1. Introduction

In these days, there has been remarkable progress in CT devices such as multi slice CT (multi-detector row CT) scanners. CT images taken by multi-slice CT scanners consist of approximately isotropic voxels (about 0.5mm cube) which involve precise information of a human body with less partial volume effect. On the other hand, significant improvement of CT image resolution forced radiologists to diagnose not only target diseases but also any kinds of diseases in any organs contained in given CT images. For example, when a doctor diagnose lung diseases like lung cancer from a 3D chest X-ray CT image, he is required to observe bronchi and blood vessel areas to know whether other diseases are existing. This task will make the doctor's load much heavier. Therefore, a computer aided diagnosis (CAD) system is strongly expected to be developed.

There are several publications about segmentation of organs in chest regions. Most of these researches are treating segmentation of bronchi, blood vessels in the lung, and aorta regions[1]-[5]. A few papers are describing extraction of aorta regions from contrasted chest CT images[4, 5]. However, an uncontrasted CT image is more suitable for the situation mentioned above since target diseases or abnormality signs to be detected are not fixed beforehand. The research for extraction of the aorta and the pulmonary artery (PA) from uncontrasted chest CT image has not been reported.

This paper proposes a method for automated extraction of the aorta and the PA from uncontrasted 3D chest X-ray CT images. Since the contrast of the mediastinum in an uncontrasted chest CT image is very low, the aorta and the PA areas are extracted without being separated by a simple region growing method as shown in Fig.1(left). To extract the aorta and the PA areas separately, we use the anatomical informa-

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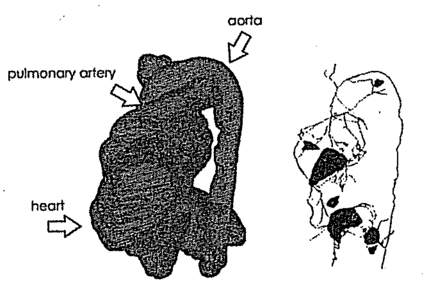

Figure 1. Extraction result of the aorta and the PA by region growing method (left) and the thinning result (right).

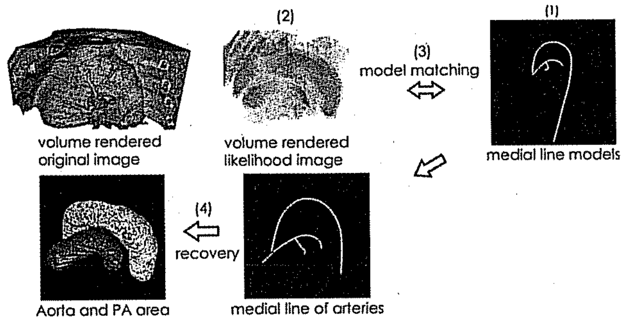

Figure 2. Outline of the proposed method.

tion that blood vessels have tube-like shapes. To utilize such information, the medial line of each vessel is required in segmentation process. However, a thinning result of Fig.1(left) has many undesired branches (Fig.1(right)) and such branches are difficult to be removed. The proposed method employs the medial line models of the aorta and the PA to extract medial lines separately, instead of performing a thinning process. Then the aorta and the PA areas are recovered from obtained medial lines.

We describe the details of the proposed method in Section 2 and show results of applying the method to actual 3D chest X-ray CT images in Section 3.

2. Medial line extraction and recovery of vessel area

Figure 2 shows the outline of the proposed method. The procedure consists of four parts : (1) construction of medial line models, (2) construction of a likelihood image, (3) model matching, and (4) recovery of each blood vessel.

2.1 Construction of medial line model

An aorta medial line model (AML model) and a PA medial line model (PAML model) are constructed manually from three cases of chest CT images in our experiment. Each model is represented by B-spline curves and their control points are allocated based on the bifurcation of the trachea. The PAML model consists of three lines. The model starts from the pulmonary trunk and ends at the right and the left PAs. The end point of the pulmonary trunk and the start points of both PAs share the branching point of the model. The AML and the PAML models are obtained by averaging the location of each corresponding control point of the models.

2.2 Construction of likelihood image

It is difficult to determine a fixed threshold value to CT values for automated extraction of blood vessel regions, since CT values in blood vessels vary widely. We use edge area of blood vessels for the more robust extraction of medial lines. First, an input image is smoothed by the median filter (mask size: $3 \times 3 \times 3$ voxels) and the opening operation[6]. Second, the magnitude of gradient at each voxel of the smoothed image is calculated. Edge candidates are extracted by executing a thresholding operation to the magnitude of gradient. Since there may be false edges extracted inside vessels, those edges are eliminated based on the standard deviation of CT values in the neighboring region (ball region of four voxels in the radius) for all candidate voxels. Edge voxels which have greater deviation values than the threshold t_σ are extracted. Thirdly, the Euclidean distance transformation[7] is performed for the non-edge area (background). Each voxel of the transformed image shows the distance to the nearest edge voxel. Voxels existing around the medial line positions have larger distance values. This means that the distance image shows the likelihood that the medial line exists on it. The likelihood image is used for the model matching.

2.3 Model matching

The proposed method extracts the AML and the PAML by deforming the models given beforehand. The AML and the aorta area are determined first, and then the PAML and the PA area are calculated. The extracted aorta area is used in the process of PAML model matching.

Each model is initially arranged based on the position of the branching point of the trachea obtained by the thresholding to CT values and connected component processing. The model matching is achieved by minimizing an energy function E defined as

$$E = w_1 E_1 + w_2 E_2 + w_3 E_3, \tag{1}$$

where w_1, w_2 and w_3 are weights for energy functions E_1, E_2 and E_3. The optimal AML and PAML that minimize E are obtained by using an iterative minimization technique (the Powell's algorithm[8]). The function E_1 represents the change of shapes between the initial state and the current state. The norm of the vector from the initial position to the current one is calculated for each control point of the B-spline curve in E_1. The E_1 becomes larger when the current shape is more different from the initial one. The function E_2 comes from the likelihood image, called the external energy. This energy becomes larger when the model is close to nearer edge areas. The function E_3 is the change of the curvature. This energy is calculated as the minimum square error between the initial curvature and the current one.

2.4 Recovery

The aorta and the PA areas are determined by applying the reverse Euclidean distance transformation to voxels on medial lines obtained above.

3. Experiment

Seven cases of 3D chest X-ray CT images were used in the experiment. Table 1 shows acquisition parameters for them. We evaluate the results by computing coincidence indices (CI) between extraction results (Region A) and regions manually traced on CT images by the author (Region B). The CI is defined as

$$CI = \frac{Number\ \ of\ \ voxels\ \ in\ \ (A \cap B)}{Number\ \ of\ \ voxels\ \ in\ \ (A \cup B)}. \quad (2)$$

3.1 Experimental results and discussion

Examples of the extraction results for Case 7 and 1 are shown in Fig.3 and Fig.4, respectively. Table 2 shows computed CI indices.

As shown in Fig.3 and Table 2, we confirmed that the aorta area are extracted satisfactorily. However, the coincidence index for Case 1 is lower than those of other cases. This is because contrast among the aorta and the PA is significantly low as indicated by white arrows in Fig.4. Therefore, the edge voxels at that part can not be obtained. The aorta area also are not be recovered correctly.

The extraction results of the PA area show 90% of CI for three cases and 80% for four cases as seen in Table 2. Main reason of lower accuracy than the aorta area is that the pulmonary trunk does not have a circular tube shape. Figure 4 shows an example of such parts. Un-circular shape is indicated by a black arrow. The proposed method recovers the PA area as a circular

Table 1. Acquisition parameters of CT images.

Image size [*pixels*]	512 × 512
Number of slices	99 – 537
Pixel size [*mm*]	0.546 – 0.625
Reconstruction pitch [*mm*]	0.5 – 1.5
Slice Thickness [*mm*]	1.0 – 3.0

Table 2. Evaluation by using CI values.

Case	Aorta	PA
1	0.88	0.82
2	0.91	0.84
3	0.92	0.92
4	0.92	0.90
5	0.94	0.81
6	0.96	0.80
7	0.95	0.92

tube with using balls of the radius r. As the radius r, we are using the distance value at the voxel on the medial line. This sometimes causes defected regions in the recovered result of the pulmonary trunk. Applying a contour model matching will improve the extraction accuracy.

4. Conclusion

We proposed a method for automated extraction of aorta and PA areas in the mediastinum using medial line models. This method extracts medial lines of each artery by medial line model matching. The aorta and the PA areas are recovered from obtained medial lines. We applied the method to seven cases of uncontrasted 3D chest X-ray CT images and compared extraction results with areas traced manually. The experimental results showed approximately 90% and 80-90% CI values for aorta and PA areas, respectively. Future work includes evaluation of the method by larger number of cases and an improvement of extraction accuracy of each artery by applying a contour model matching.

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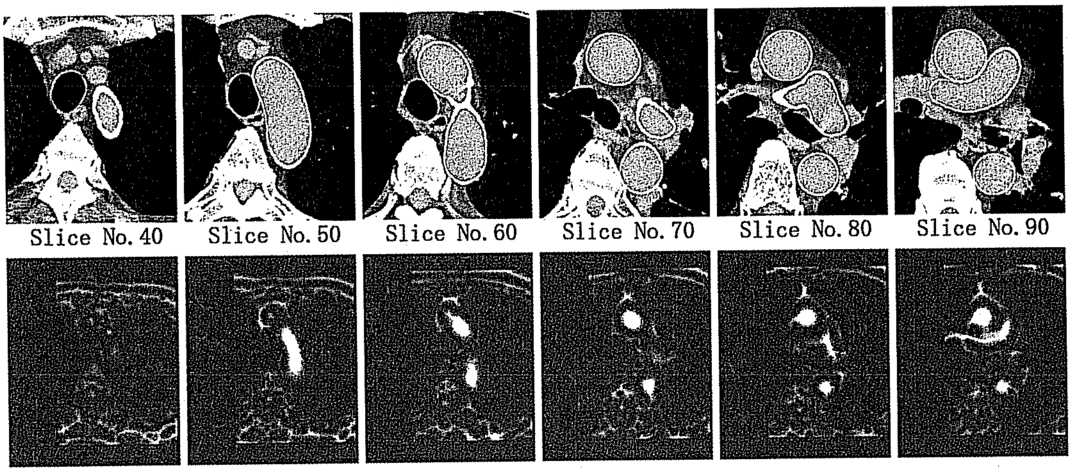

Figure 3. Examples of the extraction results for Case 7. Upper row : Contours of each vessel area overlaid on original images, Lower row : Likelihood images corresponding to upper images. Slice No.40 and No.70 contain the top of the aorta and the bifurcation of the trachea, respectively.

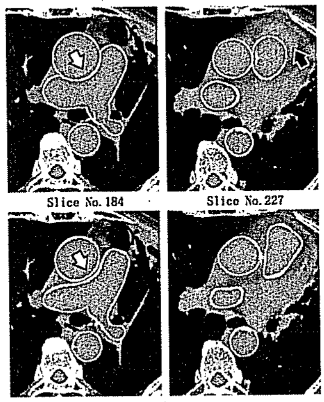

Figure 4. Examples of deteriorated extraction results in Case 1. Upper images show the extraction results and lower ones display the manual tracing results. White arrows in leftside images show the part of mis-extraction of the ascending aorta. Black arrow in the right-upper image shows the pulmonary trunk which cannot be extracted satisfactorily.

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