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# Heart Extraction and Division between Left and Right Heart from Cardiac CTA

Ho Chul Kang

*School of Computer Science and Engineering SungKongHoe University, Seoul, 08359, Korea*
hckang@skhu.ac.kr

***Abstract***

*In this paper, we propose an automatic segmentation method of left and right heart in computed tomography angiography (CTA) using separating energy function. First, we smooth the images by applying anisotropic diffusion filter to remove noise. Then, the volume of interest (VOI) is detected by using k-means clustering. Finally, we extract the left and right heart with separating energy function which we proposed to split the heart. We tested our method in ten CT images and they were obtained from a different patient. For the evaluation of the computational performance of the proposed method, we measured the total processing time. The average of total processing time, from first step to third step, was 14.39±1.17 s. We expect for our method to be used in cardiac diagnosis for cardiologist.*

***Keywords:*** *image segmentation; heart extraction; CTA; image processing; separating energy function*

## 1. Introduction

There have been many methods of image processing for a long time, including image enhancement, image denosing, image segmentation and so on [10-12]. Image segmentation is to detect specific region or divide areas in the image. In the field of medicine, it is necessary to detect some organs or tumors from medical images. Computed tomography (CT) is an imaging procedure that uses x-ray technology to produce tomographic images of specific object. To produce CT volume of data, the patient is placed into a tube. This tube emits x-rays toward the center of the cylinder. The x-rays pass through the body and the intensity is measured on the other side. Then a reconstruction work is done to actually obtain a 3D image. CT distinguishes bones better than organic tissues. The muscle and the cavities of the specific organ are not well differentiated, both appearing on close gray tones on the CT scan. CTA, CT angiography and one of medical images which have the information of the heart, is widely used in image segmentation [1] because it provides more detailed anatomic information about the organ. The disorders of the heart of blood vessels often cause cardiovascular diseases [2], and heart segmentation from CTA has been used for cardiac diagnosis. Several approaches for the automatic heart segmentation have been proposed. Olivier et al. [3] presented a heart segmentation method using an iterative Chan-Vese algorithm [4]. They used L1 fidelity term for the computational efficiency instead of L2 fidelity which is classic term. However, this approach extracted only the whole heart. Ecabert et al. [5] proposed automatic segmentation of four chambers by using statistical geometry model and training meshes from cardiac CTA images. This method required well-defined training data sets, too much time and effort to generate a template mesh. In this paper, we propose an automatic method to extract the left and right heart in CTA using k-means clustering [6] and separating energy function which we develop without any training data sets and template meshes.

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Corresponding Author: hckang@skhu.ac.kr
Tel: +82-2-2610-4282, Fax: +82-2-2610-4390
School of Computer Science and Engineering SungKongHoe University, Seoul, Korea

The remainder of the paper is organized as follows. The next section describes the proposed method of automatic segmentation of the left and right in CTA. This procedure consists of three processing steps. Section III presents the results of the proposed method to clinical dataset. In section IV, we summarize the results and discussion.

## 2. Method

*A. Smoothing Images*

First, we smooth the input CTA. In general, there is much noise in the cardiac CTA and it would not be vivid. So image smoothing is essential to segment heart region. we use anisotropic diffusion filtering [7], which minimize total variation (TV), to preserve the edge while smoothing the original image and preserves finer detailed structures in images. The equation of anisotropic diffusion filter is as follows.

$$\min \ TV = \int_{\Omega} \sqrt{u_x^2 + u_y^2}\, dxdy \quad , \tag{1}$$

where u is an image, $u_x$ and $u_y$ is the derivative of u w.r.t. x and y respectively. To discretize and optimize this equation, Rudin et al. [8] proposed a method to minimize using gradient descent PDE. Through calculus of variations, the gradient descent PDE of the minimization is as follows.

$$\begin{cases} \partial_t u = \operatorname{div} \frac{\nabla u}{|\nabla u|} + \lambda(f-u), \\ \nu \cdot \nabla u = 0 \quad \text{on } \partial\Omega. \end{cases} \tag{2}$$

Since this equation is convex, the steady state solution of the gradient descent is the global optimum. And gradient descent is performed by iterating equation (3).

$$\begin{aligned} u_{i,j}^{n+1} = u_{i,j}^n + dt\Big[\nabla_x^-\Big(\frac{\nabla_x^+ u_{i,j}^n}{\sqrt{(\nabla_x^+ u_{i,j}^n)^2 + (m(\nabla_y^+ u_{i,j}^n, \nabla_y^- u_{i,j}^n))^2}}\Big) \\ + \nabla_y^-\Big(\frac{\nabla_y^+ u_{i,j}^n}{\sqrt{(\nabla_y^+ u_{i,j}^n)^2 + (m(\nabla_x^+ u_{i,j}^n, \nabla_x^- u_{i,j}^n))^2}}\Big)\Big] + dt\lambda(f_{i,j} - u_{i,j}^n), \quad i,j = 1,\ldots,N-1 \end{aligned} \tag{3}$$

*B. Extracting the Whole Heart*

This step extracts the whole heart including the left and right heart region using thresholding and k-means clustering. And we expand the heart region by comparing the mean CT value of each cluster. So the clusters are removed as cardiac muscles and the other clusters are merged (see Figure 1).

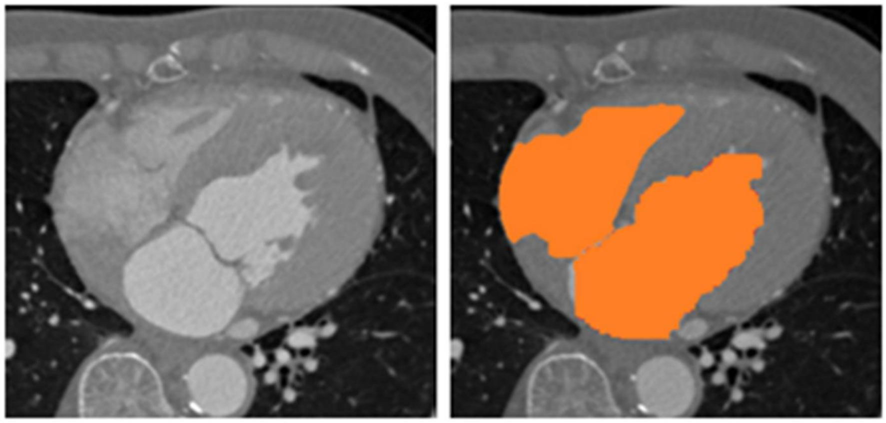

**Figure 1. The result of the whole heart extraction. The input image(left) and the result of segmentation (right).**

*C. Separating the left and right heart from the Whole Heart*

In this step, we split the heart into the left and the right heart from the clustered mask volume, the output of the previous extracting the heart region step. It is hard to divide the heart into the left and the right heart automatically, because there is ambiguity in the boundaries or difference between them. So we minimize the separating energy function for splitting the heart into the left and right heart. We propose the separating energy function as follows.

$$E = \alpha \cdot Area\ Energy + \beta \cdot Intensity\ Energy \tag{4}$$

where α and β is weights of the area energy and intensity energy respectively, the area energy is the area of intersection with the separating plane and heart region, and the intensity energy is the bright value of the intersection plane.

$$\begin{aligned} &Area\ Energy = \int_{\Omega_M} H(\mathrm{mask(x)})\,dx, \\ &where\ \ H(t) = \begin{cases} 1, & t \neq 0 \\ 0, & otherwise \end{cases}, \end{aligned} \tag{5}$$

where mask(x) is the function of mask function from the heart extraction, and H(t) is the binary function w.r.t t value.

$$Intensity\ Energy = the\ \ mean\ \ value\ \ of\ \ bright\ \ values\ in\ \ the\ \ heart\ \ region \tag{6}$$

To split the heart into left and right heart, we minimize the separating energy function E. We obtain the minimum by calculating using Powell's method [9]. Figure 2 shows that the process of the optimization for separating the heart into left and right using separating energy function and Powell's method. The position and orientation of the separating plane is detected using iterative optimizing process.

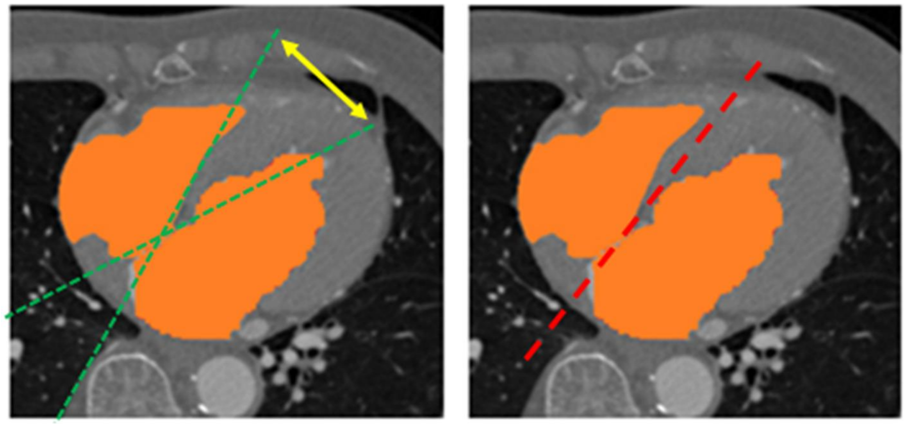

**Figure 2. The detection of the separating plane for the left and right heart. The whole heart image and mask (left, the green dotted lines are candidates of the separating plane) and the result of the optimization (right, the red dotted line is the separating plane).**

## 3. Experiments and results

We tested our method using the system which has the Intel® Core™2 Quad 3.4 GHz processor, 16 GB of main memory and Windows 10. We extract the left and right heart from ten CT images and they were obtained from a different patient. The numbers of images per scan ranged from 192 to 227. Each image had a matrix size of 512 × 512. The voxel size was 0.36. Figure 3 shows the result of the left and right heart segmentation and Table 1 shows the computational time for each step. For the evaluation of the computational performance of the proposed method, we measured the total processing time. The average of total processing time, from first step to third step, was 14.39±1.17 s. In figure 3, the area of blue is the region of right heart, and the area of red is the region of left heart. In addition, we extract an iso-surface from the result of the segmentation and rendered it (see Figure 3).

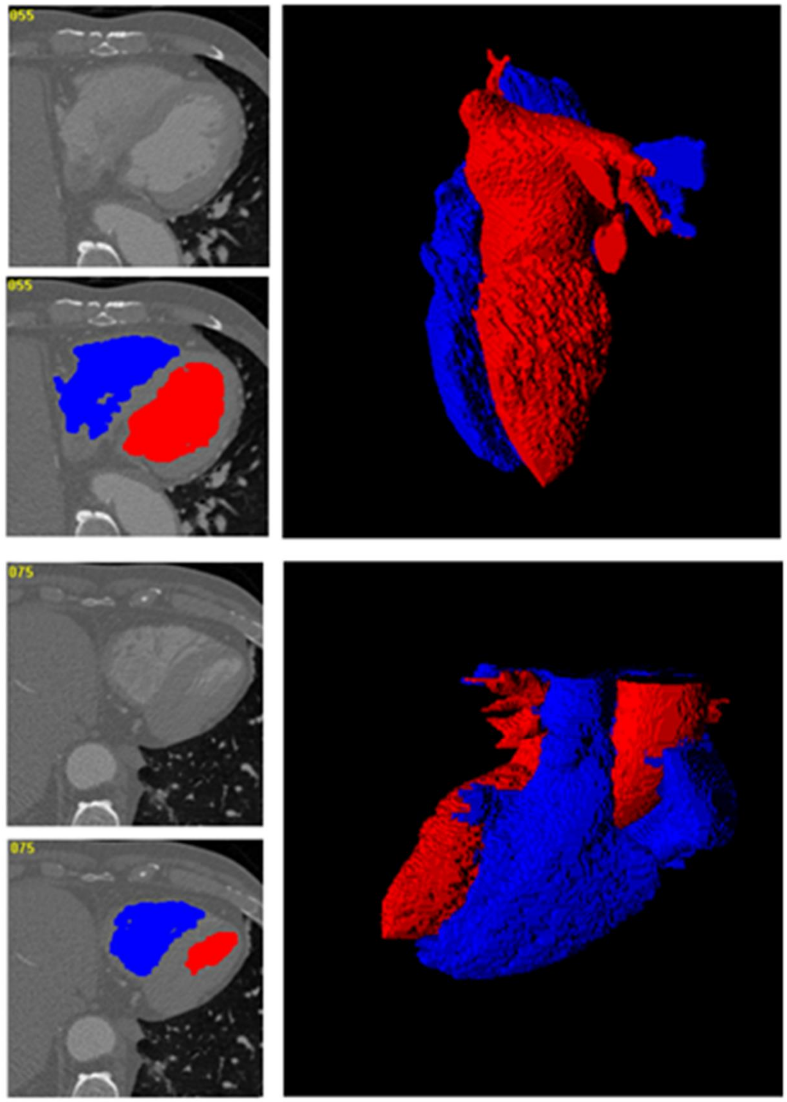


**Figure 3. The result of the left and right heart segmentation. The input image(left top), the result of segmentation (left bottom) and the iso-surface extraction (right).**

**Table 1. Computational Time for Each Segmentation Step(sec)**

| Data | Smoothing image | Extracting heart | Separating heart | Total |
|---|---|---|---|---|
| 1 | 5.5 | 1.7 | 5.4 | 12.6 |
| 2 | 6.2 | 2.1 | 5.8 | 14.1 |
| 3 | 5.7 | 1.6 | 5.5 | 12.8 |
| 4 | 7.1 | 2.3 | 6.7 | 16.1 |
| 5 | 6.1 | 1.9 | 6.2 | 14.2 |

| Data | Smoothing image | Extracting heart | Separating heart | Total |
|---|---|---|---|---|
| 6 | 7.5 | 2.7 | 6.4 | 16.6 |
| 7 | 5.3 | 2.1 | 5.7 | 13.1 |
| 8 | 6.7 | 2.0 | 5.9 | 14.6 |
| 9 | 7.3 | 2.5 | 6.3 | 16.1 |
| 10 | 6.2 | 1.5 | 6.0 | 13.7 |

## 4. Conclusion

It is difficult to segment the heart because the chambers of the heart have weak edge or no edge. This paper presented a segmentation method of the left and right heart region using k-means clustering and separating energy function. This method is expected to be used in cardiac diagnosis.

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