A Novel Approach of Cardiac Segmentation In CT Image Based On Spline Interpolation

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Abstract. Organ segmentation in CT images is the basis of organ model reconstruction, thus precisely detecting and extracting the organ boundary are keys for reconstruction. In CT image the cardiac are often adjacent to the surrounding tissues and gray gradient between them is too slight, which cause the difficulty of applying classical segmentation method. We proposed a novel algorithm for cardiac segmentation in CT images in this paper, which combines the gray gradient methods and the B-spline interpolation. This algorithm can perfectly detect the boundaries of cardiac, at the same time it could well keep the timeliness because of the automatic processing.

1. Introduction

The x-ray computerized tomography (CT) provides a 2D map of details of the organs which are the linear attenuation coefficient mirroring morphological. It is a high spatial resolution and wide dynamic range imaging modality. The X-ray absorption levels of organs and tissues in CT images are represented by different gray. Thus, as the black and white areas shown in X-ray images shadows, the black shadow reflect the low absorption area, representing to low-density areas, such as lungs with gas; white shadow reflect the high absorption areas, representing to high-density areas, such as the skeleton.

In CT image the cardiac are often adjacent to some tissue, such as the parietal, and their gray-scales are within proximity to each other, meaning that there are not obvious gray gradient in the boundary. Because the classical method such as histogram distribution method, Genetic Algorithm, Seed algorithm, ASM (Active Shape Model) and ACM (Active Contour Model) are all based on the clear gray gradient, it may not deal with this problem effectively. At the same time, there are many false contours and boundaries in the image causing by the object’s movements and random noise resulting from the external field interference. What is more, with analyzing the Series images, besides above features, we found another characteristic that the contours of cardiac and parietal change gently.

Based on these image characteristics, we proposed a new algorithm to achieve heart segmentation. In this algorithm, it could select samples on both sides of the parietal automatically, and then utilize these samples to fit the contour of upper heart, which are adjacent to the parietal, using the spline interpolation theory. We chose the B-spline interpolation to fit those samples. B-spline interpolation is
a kind of numerical analysis by nature. The idea of this method is predicting the unknown contours, with selecting samples on the existing or readily available contours. It matches with those three features definitely.

2.1 B-spline Interpolation

B-spline interpolation is one significant technology in the interpolation & fitting theory, it belongs to the numerical analysis area apparently. The main idea of interpolation is using the samples to predict the unknown, but relative data. The method concludes the interpolation polynomial method, difference quotient method and spline curve method. B-spline curve is a common technology about spline curve method, it can be always utilized to construct a smooth curve, and widely applied in the computer graphics and CAD (computer-aided design) area.

To ensure the accuracy and save the cost of computation, it always chooses the cubic B-spline curve. In this paper, we also chose the cubic method: assume that sample points are \( P_i = (x_i, y_i), i=0, 1, \ldots, n \), the Cubic B-spline can be described as follow:

\[
B_i(u) = \sum_{k=-2}^{2} b_k P_{i+k}
\]  

In the formula, \( P_i \) represents the \((x_i, y_i)\) point, \( b_k \) is the vector base, it doesn’t vary regardless of the changes of sample, it is also the weight values. With the weight factor evolving from 0 to 1, B spline interpolation can be obtained using weight sum.

In the cubic B-spline interpolation, the values of \( b_k \) could be expressed with the matrix as fellow:

\[
B_i(u) = \frac{1}{6} (u^3, u^2, u, 1) \begin{pmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{pmatrix} \begin{pmatrix} P_{i-1} \\ P_i \\ P_{i+1} \\ P_{i+2} \end{pmatrix} = \frac{u^3 N_{i,3}}{6}
\]

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2.2 Boundary detection algorithm based on LoG operator

LoG(Laplace & Gauss) algorithm utilizes zero cross points of the second derivative to get the object boundary, considering the local maximum of first derivative correspond to the zero cross points. Assume that the original image is \( g(x,y) \), we can get output of the LoG operator with the expression as

\[
h(x, y) = \nabla^2 [G(x,y) * g(x,y)]
\]

Apply the Convolution theorem to the expression, it can be written as

\[
h(x, y) = [\nabla^2 G(x,y)] * g(x,y)
\]
\( \nabla^2 \) is the Laplace operator.

\[
\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}
\]

\( G(x, y) = \frac{1}{\pi \delta^2} \cdot \frac{-x^2 - y^2}{\delta^2}
\]

Then, \( \nabla^2 G(x, y) \) can be given by

\[
\nabla^2 G(x, y) = \frac{\partial^2 G(x, y)}{\partial x^2} + \frac{\partial^2 G(x, y)}{\partial y^2} = \frac{1}{\pi \delta^2} \left( \frac{x^2 + y^2}{\delta^4} - 1 \right) \cdot \frac{-x^2 - y^2}{\delta^2}
\]

For those discrete digital images, LoG operator can often be approximated by a discrete LoG template \( m(x, y) \). Parameter δ is related to the template width \( \omega \). Their relationship could be described as bellow: if \( \omega \) is smaller compared to \( \delta \), the boundary location can be more accurate, meaning that more slight changes can be detected, on the contrary, if \( \omega \) is bigger compared to \( \delta \), the boundary detected will deviate from the original boundary location, and some significant details could be lost.

Fortunately, there are empirical formula to determine the value selection of \( \omega \) and \( \delta \). Thus, we could calculate the LoG template \( m(x, y) \) based.

For the discrete digital image, we can approximate the output of the LoG operator as follow:

\[
h(x, y) = m(x, y) \ast g(x, y)
\]

With applying the LoG operator, the output \( h(x, y) \) of low gray value will be greater than zero, the output \( h(x, y) \) of high gray value will be less than zero conversely. Then the boundary of original image comes out definitely as zero track of the output \( h(x, y) \).

2.3 Determine the threshold and binarization

At first we could count the all the pixels of boundary points, and then calculated the average value \( Th \), and set the \( Th \) as threshold.

Then we can binarize the original image with the following formula:

\[
bw(x, y) = \begin{cases} 
1 & \text{if } g(x, y) \text{ is in the area} \\
0 & \text{if } g(x, y) \text{ is out of the area}
\end{cases}
\]

\( bw(x, y) \) is the binarization of the image

3 Specific steps and results:

Because the gray values of parietal and pulmonary have high contrast, we can use those classical segmentation methods to detect the boundary. In this algorithm, we chose the Log algorithm (Laplace
and Gauss) to detect the boundary and extract those eight neighborhood connecting points, and finally extracted the coordinate of each point.

Our aim is to select some uniform sample points on the Parietal, so the choice of samples is based on the spatial characteristics of the lung boundary, if necessary, we should take one or two more points in the upper of heart to amend the direction of curve, this means adding the prior experience of human, which can contribute the accuracy to the segmentation result definitely. Specific Procedure is bellow:

1) Eliminate some of higher contrast regions, use method of histogram equalization to enhance the contrast of image; 2) Apply the threshold segmentation and binarization methods to obtain contour of lungs, which is part of the parietal; 3) Select uniform samples on the parietal based on Spatial feature, and take one or two samples on the upper of heart interactively; 4) Store coordinates of these sample point, then apply B-spline interpolation method to obtain the upper boundary of the cardiac; 5) Utilize the classical algorithms on the image to obtain the lower boundary of the cardiac; 6) Combine these two part boundaries of the cardiac into one integral boundary.

Figure 1

(a) Origin image  (b) After histogram equalizing  (c) Lung segmentation with LoG

Figure 2

(a) Sample points  (b) interpolation and fitting curve
Figure 2(a) is the enhanced image with selected points; Figure 2(b) is the upper boundary of cardiac with applying B-spline interpolation and fitting;

(a) The lower part boundary of cardiac  (b) The complete boundary  (c) The extraction of cardiac

Figure 3

Figure 3(a) is the lower part boundary of the cardiac; Figure 3(b) is combination of those two boundaries, which is definitely the boundary of cardiac; Figure 3(c) is the heart binarization image, it is definitely the foundation of 3D reconstruction

Conclusion

In this article, we introduced a noble cardiac segmentation algorithm in CT images. This algorithm is mainly based on the gray gradient methods and the B-spline interpolation method. In the algorithm, some sample points were chosen based on the spatial information of heart, most of them are chosen automatically, one or two sample points are taken interactively to amend the trend of spline if necessary. From the results given above, it can extract heart contour from CT image effectively and premise the timeliness well. The next step of our work is to adjust the parameters to achieve all the segmentation from the series of CT images, the data obtained will be used for the heart 3-D reconstruction.

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