

Left Ventricle Segmentation Technology based on CV Level Set Methods

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Abstract

This paper presents an improved contour extraction method based on CT images of the left ventricle. It provides the basis for three-dimensional and four-dimensional reconstruction of post-cardiac imaging. In this method, original CT image will be segmented by CV level set methods after the pre-treatment of the image firstly, and we derive boundary point set from energy function minimization information; then we gain the global contour lines dataset which contains multiple contours. Finally, we accurately extract the outline of the left ventricle based on the determinant conditions of area and so on after excluding one-point outline. Experimental results show that this method can effectively extract the left ventricle smooth continuous contour in the environment of fuzzy boundary information and topology changing.

Keywords

CT images, left ventricle, CV model, level set, contour extraction, area information.

1. Introduction

Heart disease is recognized as one of modern society killers. Left ventricular systolic and diastolic dysfunction is the first result of heart failure because that the systolic pressure of the left ventricular provides power for the heart. Studies have shown that abnormal left ventricular function is the cause of most cardiogenic circulatory failure [1]. In order to detect and prevent heart disease effectively, it has been studied to assess left ventricular function from more than one way and the use of CT images is one of the important means. However, it's unable to get the specific location, volume size and the geometric shape of the region which is interested in the three dimensional space [2] and its diagnostic accuracy is also affected by the doctor's experience.

We need to get the 2d contour data before 3d reconstruction for interested areas and then 3d grid data can be obtained by each contour line [3]. The left ventricle CT images have the characteristics of uneven gray, papillary muscle interference, weak boundary and the change of topological structure, etc. To get a better segmentation of CT images of the left ventricle, the method we used must be able to well deal with the characteristics of interference above.

There are lots of left ventricle CT image segmentation methods. However, parameter active contour model represented by snake model generally does not support topology changes [4, 5] while region growing method relies too much on the selection of seeds[6]. Threshold method is easy to implement, but difficult to deal with the situation of topology changing and fuzzy grey information, and particularly sensitive to noise [7]. Clustering algorithm has high computational complexity so that its use has conditionality [8]. So these problems have restricted their application in 3D reconstruction and 4D cardiac CT images[9].

To solve above problems, this paper developed an improved method of outline extraction based on CV level set, which can well deal with the fuzzy boundary problem and has a good segmentation effect for the left ventricle CT images with fuzzy grey information, complex shape and topology changing. It can accurately segment the outline of the left ventricle which is continuous and smooth.

2. Image Preprocessing

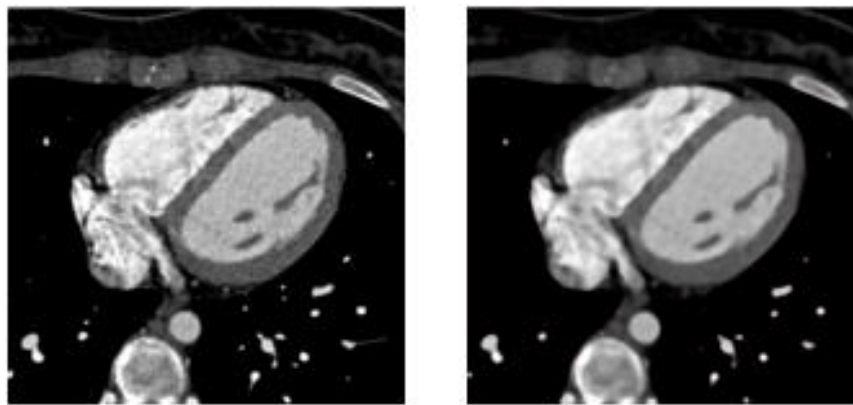
2.1 DICOM Format Conversion

The DICOM standard is widely used in various types of medical instruments so as to realize digital image transmission. We must convert to the format which can be directly used, such as BMP format, because DICOM format images cannot be read by most image processing software [10].

2.2 Image Filtering

Filtering operation can reduce image noise while try to retain the image details. Median filtering, gaussian filtering and average filtering are common filters. Median filtering, a nonlinear filter, can protect image edge information, and is more applicable in the cardiac CT image processing. The output of it is the median of 2D sliding window containing an odd number of points. It can be implemented in Matlab by Medfilt2() function.

Fig. 1 (a) is a piece of untreated CT images and Fig. 1 (b) is a piece of CT images after median filtering processing. From here we see that the noise of CT images has decreased significantly after pretreatment and the contrast has been improved. The target edge becomes clearer because of the well preservation of boundary information. The CT images after pretreatment are more suitable for the next steps.



(a) a piece of untreated CT images

(b) a piece of CT images after preprocessing

Fig.1 Image contrast before and after pretreatment

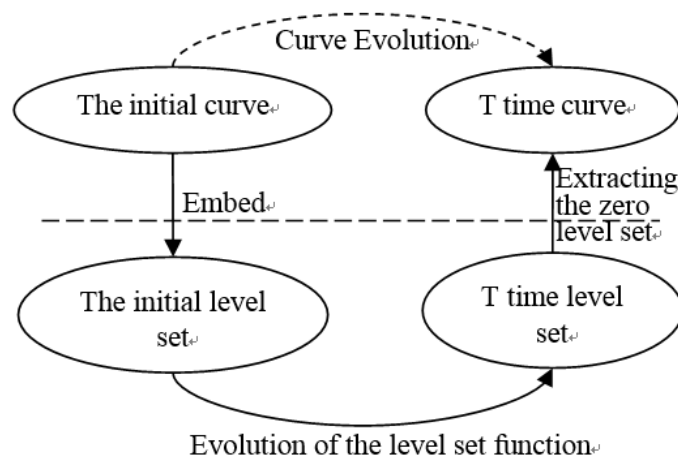


Fig.2 Curve evolution and the evolution of the level set function schematic

3. Image segmentation

3.1 The theoretical method based on CV level set.

Level set method turns the evolution problem of n-dimensional surface into the level set function surface evolution problem of n+1-dimensional space and it uses the implicit way to solve the problem[11]. We might as well take 2-dimensional curve as an example that it will be regarded as the zero level set of 3-dimensional surface $\phi(x, y)$ (Zero level set is usually $\{\phi=0\}$ and $\phi(x, y)$ is called the level set function). The shape of the curve can be embedded in the 3-dimensional surface and the evolution problem of the surface can be solved through this kind of implicit way.

Chan and Vese[12] proposed a level set image segmentation method based on Mumford-Shah function. It's called the CV model which can deal with fuzzy boundary problem effectively. CV level set model can be represented as:

$$\begin{aligned}
 E(c_1, c_2, \Phi) &= \varepsilon_1(c_1, c_2, \Phi) + \varepsilon_2(c_1, c_2, \Phi) \\
 &= \lambda_1 \iint_{\Omega} (I - c_1)^2 H(\Phi) dx dy \\
 &\quad + \lambda_2 \iint_{\Omega} (I - c_1)^2 [1 - H(\Phi)] dx dy \\
 &\quad + \nu \iint_{\Omega} B(x, y) \delta_{\varepsilon} |\nabla \Phi| dx dy
 \end{aligned} \tag{1}$$

We plug the boundary function $B(x, y)$ defined by the gradient information into formula(1). And then the level set function evolution equation based on the CV model can be obtained.

$$\begin{aligned}
 \frac{\partial \Phi}{\partial t} &= \delta_{\varepsilon} [-\lambda_1 (I - c_1)^2 + \lambda_2 (I - c_2)^2] \\
 &\quad + \nu \delta_{\varepsilon} \left[\operatorname{div} \left(g \frac{\nabla \Phi}{|\nabla \Phi|} \right) + g \right]
 \end{aligned} \tag{2}$$

Wherein, λ_1 , λ_2 and ν are constant parameters and they are used to control the evolution effect of regional information item and boundary information item respectively. The effect of segmentation can be adjusted by changing the parameter. c_1 and c_2 , calculated by formula(3), (4) and (5), represent the mean gray values of the image inside and outside the area. The unit impulse function $\delta(x)$ is defined as Equation (6).

$$c_1 = \frac{\int_{\Omega} I * H(\Phi) dx dy}{\int_{\Omega} H(\Phi) dx dy} \tag{3}$$

$$c_2 = \frac{\int_{\Omega} I * (1 - H(\Phi)) dx dy}{\int_{\Omega} (1 - H(\Phi)) dx dy} \tag{4}$$

$$H_{\varepsilon}(x) = \frac{1}{2} \left(1 + \frac{2}{\pi} \arctan\left(\frac{x}{\varepsilon}\right) \right) \tag{5}$$

$$\delta_{\varepsilon}(x) = \frac{1}{\pi} * \frac{\varepsilon}{\varepsilon^2 + x^2} \tag{6}$$

3.2 Main parameter settings

The main parameters needed to be configured include: the location and size of initial contour, time step, constant parameter Settings and the coefficient of Heaviside and Dirac function, etc.

The location and size of initial contour

The segmentation effect of level set method is extremely sensitive to the location of the initial round. The experiment proved that we can get good segmentation effect when the initial round is placed in the center of the left ventricular. The initial round should stay away from the obvious gradient information, otherwise the segmentation effect is not satisfied. The program code is as follows:

```
ic=nrow/a; %Center position is set by X and X
jc=ncol/b; % a represents the vertical position and b represents the horizontal position. Middle value
is 2
r=c; %Used to adjust the initial contour radius size
```

Time step

Delta_t is mainly used to adjust the iteration time. The bigger delta is, the faster the zero level set curve evolution is.

Constant parameter Settings

Lambda_1, lambda_2 respectively corresponds to the constant parameters λ_1 and λ_2 in the evolution formula (2) and they are the regional information adjustment parameter. The general experience value of Lambda_1 is 0.3. The evolution curve is not sensitive to the boundary information when Lambda_1 is big. The general experience value of Lambda_2 is 0.8. The evolution curve is not sensitive to the boundary information when Lambda_1 is small.

The coefficient used to calculate the Heaviside and Dirac function

The coefficient used to calculate the Heaviside and Dirac function is epsilon. The bigger it is, the more boundary information is ignored. The general experience value of epsilon is 0.3.

In the following discussion, if not specified, the initial contour is placed in an appropriate place, and the parameters are set the same parameter.

3.3 The process of curve evolution

Updating the level set function can be implemented by sub-function evolution_cv which is called cyclically by FOR loop. The level set function of the whole image can be calculated by sub-function evolution_cv and zero level set at each time can be calculated by sub-function plotLevelSet.

Main program is as follows:

```
for k=1:d
phi=evolution_cv(I, phi, mu, nu, lambda_1, lambda_2, delta_t, epsilon, numIter);
if mod(k,10)==0
pause(.5);
imagesc(uint8(I));
colormap(gray)
hold on;
M=plotLevelSet(phi,0,'b') ;
end
end;
```

The main update statement in sub-functions evolution_cv is:

$$\text{phi}=\text{phi}+\text{delta_t}*\text{delta_h}*(\mu*\text{Curv}-\text{nu}-\text{lambda_1}*(\text{I}-\text{C1}).^2+\text{lambda_2}*(\text{I}-\text{C2}).^2);$$

Among them, $\text{delta_h}=\text{Delta}(\text{phi},\text{epsilon})$ and Curv is the curvature of the evolution curve (obtained by internal calculation). The left side of the equation is the level set function after the update, and the right side is the level set function at last time. Sub-functions plotLevelSet is implemented by function contour. The update of the level set function relies on FOR loop, and its termination condition is $k(k=1:d)$. d is the update frequency of the level set function. Experiments show that we can take speed and effectiveness into consideration when d takes 160.

4. Improved selection and display of the left ventricle contour

Level set evolution is controlled by a preset number of iterations. The contours of the entire cardiac CT image will be segmented if the number of iterations is set to more than enough. This paper puts forward a kind of left ventricular contour selection method based on the judgment condition. The experiments show that the method is convenient and accurate.

Method is as follows:

We first create an empty matrix. And then the elements are set to 255 according to M while the other is set to 0. Since the coordinates of the evolution curve are all stored in the variable M, $M = \text{plotLevelSet}(\phi, 0, 'b')$, we want these coordinates stored in a $512 * 512$ empty matrix. It is worth noting that, the coordinates stored in M are not all integer values. The values are reserved to four decimal places, so they need to be rounded before being stored in the matrix.

8-neighborhood search method is used to save each separate contour curve into S_1-S_n . The method searches a binary image(the elements are set to 0 and 255) from left to right, top to bottom. When confronted with a value of 255 for the first point 8-neighborhood search starts working. We set the gray value of the searched pixels to 0 and store their coordinates. Search point will jump back to the first point which its value is 255 when the search of the current contour is completed. Then the method continues to search the binary image from left to right, top to bottom until the end. Since the pixels of the first contour are set to 0, it will no longer be retrieved.

In the case of ensuring a sufficient number of iterations, we select the target contour by area judgment and then draw it. Calculating the area of each contour is achieved by function $a = \text{polyarea}(x, y)$. We need to transform the format of each contour from $n*2$ to $2*n$ and the two row values are stored as x and y before using function $a = \text{polyarea}(x, y)$. Secondly, the obtained area of each contour will be sequentially stored in the area matrix. Finally, we choose the area of left ventricular contour came in the second largest using the Sort function.

Adding the contour judging of single point to exclude it makes so that the success rate of segmentation can be greatly increased. Since the level set segmentation can achieve sub-pixel accuracy, the contours should be deposited into the empty matrix to the nearest whole number and it will bring a problem. Accurate continuous curve obtained by level set segmentation will get more complex in some parts with complex gray information. We deposit it into the $512 * 512$ matrix by the above method and its boundaries may appear ghosting. This will lead to a phenomenon that a point may be saved as a separate contour mistakenly. An error will occur while using the Ployarea function to calculate the area. In order to solve the problem and improve the success rate of segmentation, this article add a judge to exclude the single point contour before the contours are saved into the separate variable S_i .

The total flow of the improved method of outline extraction based on CV level set is shown in Figure3.

5. Experimental results and analysis

Cardiac CT images of the experiment are captured by Siemens SOMATOM Definition systems and their size are $512 * 512$. The image parameters are as follows: window level = 200, window width = 600, tube voltage = 120kV, tube current = 652mA. In this paper, algorithms are implemented on Matlab 2011b. Computer configuration is as follows: Intel Core 2 Duo CPU, 2.2 GHz and 4GB RAM. Program parameters are set as follows: $a=2.2, b=1.6, r=10, \Delta t=40, \lambda_1=0.3, \lambda_2=0.8, \epsilon=1$.

In this paper, five groups of CT images were selected for the experiment according to a certain interval and each group has 53 images. Figure 4 shows the segmentation results of six images. This six images come from the same group of CT image during systole. Its selection rule is $N=1+n*10$, where $n=0\sim 5$. Since the myocardium will shrink in systole, there are more wrinkles on the surface of the myocardium. Boundary gradation information are more complex than that in diastolic and CT

images in systolic are harder to be segmented. Using the proposed algorithm for image segmentation which can achieve better results proves its applicability is strong. As can be seen from the figure, the left ventricle segmentation algorithm proposed in this paper has a good effect.

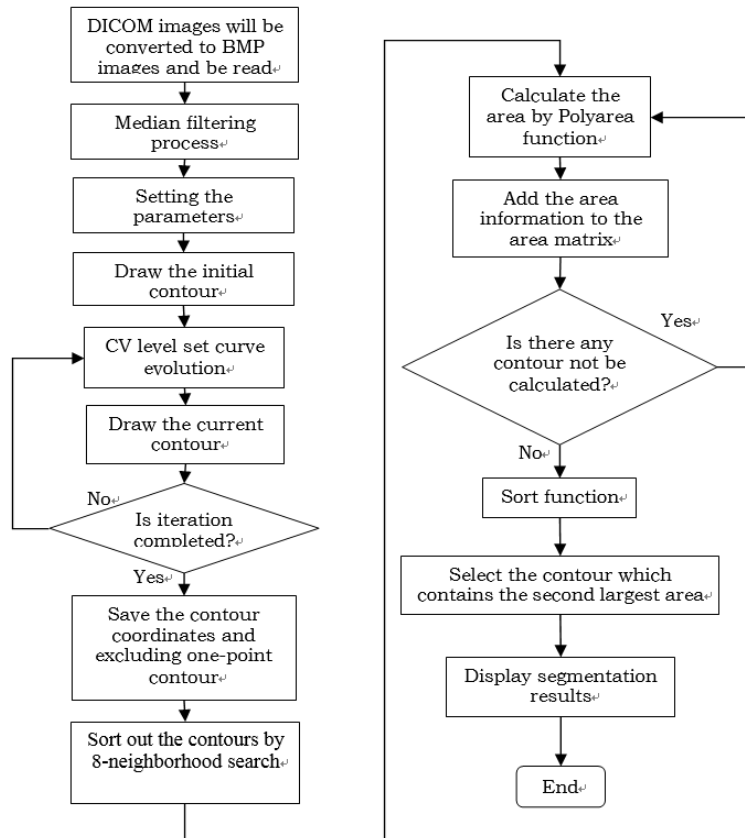


Fig.3 Method for total process

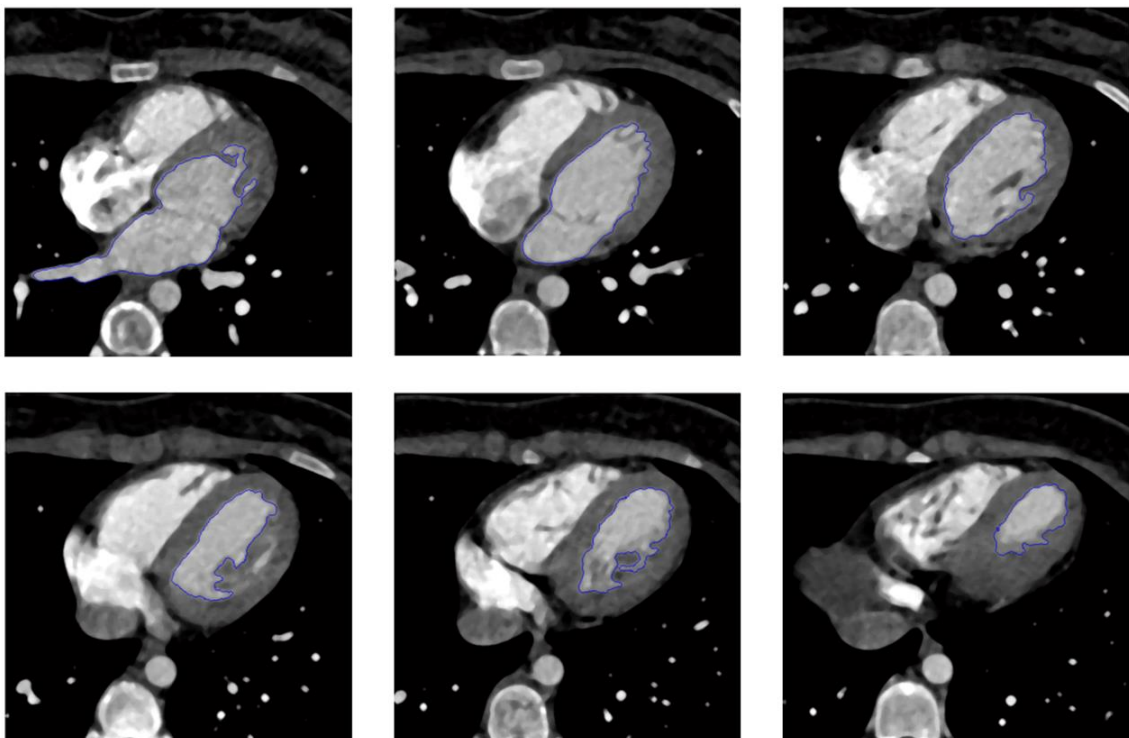


Fig.4 Segmentation results of cardiac CT images at the same time using the method discussed in this article

Figure 5 shows the contour extraction results of CT image using different image segmentation method. Figure 5 (a) is the original cardiac CT image. Figure 5 (b) shows the image using the parameter activity model based on snake method and the segmentation results is not satisfactory. Figure 5 (c) shows the effect of the contour using thresholding method. This method can not accurately identify the information of fuzzy boundaries of information and can not get a complete contour. What's more, the boundary contour obtained by this method is not smooth. Figure 5 (d) shows the result obtained by the algorithm proposed by this paper. After comparison we can find that the proposed method can well handle the fuzzy boundary problem. For the images which have fuzzy boundary information and topology changing, good segmentation results can be guaranteed. We can accurately sort out the smooth continuous contour of left ventricle.

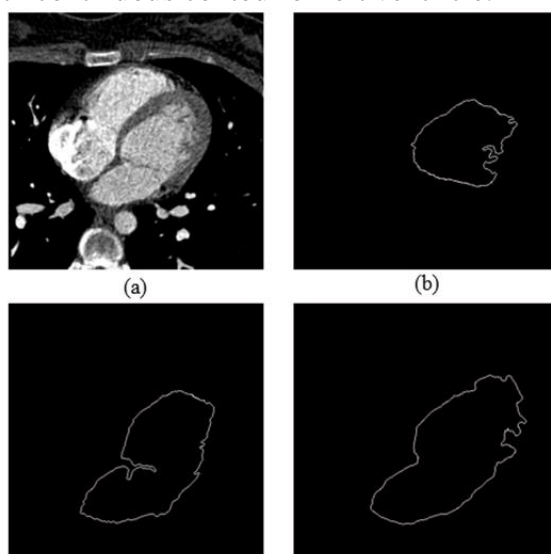


Fig.5 Contour extraction contrast using different segmentation methods

In this paper, we use the proposed algorithm experiments on five sets of CT images and have a success rate statistics, as shown in Table 1. With the number of group increases, the cardiac CT images present the process of systolic to diastolic. Experimental results show that the algorithm can get ideal data which proves the improved left ventricular segmentation algorithm has higher feasibility and more general applicability.

Table 1 The results of segmentation success rate at different times

Groups of CT images	The number of CT images	Success rate
1(Systolic)	53	94.33%
2	53	96.22%
3	53	100%
4	53	98.11%
5(Diastolic)	53	100%

6. Conclusion

This paper studies the CT image of the left ventricle and propose an improved method of image segmentation based on level set CV to extract the left ventricle boundary contour. The method of calculating the minimum energy function is used to complete the image segmentation by CV level set. Therefore, the method has the global optimum characteristics. It overcomes the dependence on the gradient information of the previous methods and can better respond to topology changes. The segmentation result is accurate, robust and sub-pixel accuracy. When it comes to contour extraction, this paper has proposed a left ventricular contour extraction method based on conditions. In this step, we use 8-neighborhood search method to sort out the contours and store them separately. Then the way of selecting contour with the second largest area based on the control of iterations would be used

to achieve the purpose of extracting after eliminating the single point contour. The experimental results show that this method can extract a clear, accurate, smooth and continuous contour of left ventricle on the premise of a certain speed. The diagnosis and treatment of clinical cardiology, the effective left ventricular contour extraction method can improve the quality of three-dimensional reconstruction. Doctors can intuitively and accurately read the required parameters calculated by the heart model based on three-dimensional reconstruction, such as end-diastolic/end-systolic volume, every cardiac output and cardiac output, etc. It makes the doctor to get rid of the limitations of experience and is of great significance to the discovery and prevention of heart disease. What's more, it is the necessary step of four-dimensional cardiac imaging which is based on the three-dimensional images of the heart and the time information of cardiac cycle. Four-dimensional cardiac imaging do great help with the heart disease diagnosis from a new angle as well as improving the accuracy of diagnosis.

Acknowledgements

International S&T Cooperation Program of China(ISTCP)(2015DFI12970).

Guangdong - Hong Kong Technology Cooperation Funding Scheme(2013B010136002).

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