AUTOMATED SEGMENTATION AND TRACKING OF CORONARY ARTERY FROM ECHOCARDIOGRAPHIC SEQUENCE USING HOUGH TRANSFORM AND SHAPE MODELLING

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ABSTRACT

Automatic segmentation and tracking of coronary artery from ultrasound sequences is an important step in computer aided diagnosis of cardiac disease. This paper presents an automatic approach of segmentation and tracking of coronary artery in ultrasound image sequences. There are two steps in proposed approach including automatic detection and segmentation in sequences based on Hough Transform and shape modeling framework respectively. The detection step provides initial localization of the contour close to the coronary artery which indicate the outline of whole artery. Then active contour is used to segment the accurate boundary of the coronary artery in the first image of temporal sequences based on the initialized outline. To track the artery in image sequences, an improved shape modeling based algorithm is used to propagate in image sequences using image gradient prior. Experiments are performed on cardiac ultrasound sequences containing longitudinal coronary artery. The results show that the proposed algorithm provides a reliable way to segment and track coronary artery in ultrasound image and can be used in computer aided diagnosis of cardiac disease.

***Index Terms*—** Echocardiographic Sequences, Hough Transform, Active Contour, Shape Modeling, Ultrasound Tacking, Computer Aided Diagnosis

1. INTRODUCTION

Among medical imaging techniques, ultrasound is particularly attractive because of its good temporal resolution, non-invasiveness and relatively low cost. However in clinical practice, analysis of ultrasound still relies on manual outlines produced by expert physicians. Although manual analysis is used so much in clinic, this process of manual outlining is time-consuming and complicated. Computer assisted techniques can provides more efficient and accurate processing for ultrasound image analysis [1]. Automatic coronary artery segmentation and tracking from cardiac ultrasound image is important in clinical practice, where visualization and measurement tools often rely on the processing results. However, robust segmentation is particularly challenging in case of the ultrasonic image because of poor quality of ultrasound image, especially in case of tracking 2D + T changes in echocardiography [2].

Until now, several segmentation and tracking approaches of cardiac boundary from ultrasound image sequences have been proposed in literatures [3][4][5]. Mikic et al. proposed an active contour frame where propagation of a fitted contour from one frame to another was guided by optical flow estimates [6]. The result is promising by evaluating the performance on eight echocardiographic sequences. However, for very irregular and large displacements, this approach may fail to compute the displacement and a prior knowledge is needed to improve the performance. Mitchell et al. developed a three-dimensional active appearance model for segmenting 2-D echocardiography sequences [7].This approach is deemed successful in 57 of the 64 datasets. The limitation of this method is the endocardia average distance error is not small enough due to the extract degree of freedom. Alex et al. proposed an automatic vessel tracking and segmentation frame work to track vessels from ultrasound sequences with the purpose of enabling stenosis quantification[8]. An average accuracy of 92.86% of detection and 78.51% of the segmentation were assessed as correct.

2. METHODS

The input for the proposed algorithm is ultrasound image sequences incorporating the longitudinal coronary artery. The workflow of the segmentation and tracking process is summarized in Fig.1 and as follows: In the original image sequences the Hough Transform algorithm is used to detect the outline of artery lumen. Then accurate boundary of artery lumen is segmented using active contour algorithm from one of the 2D ultrasound image in given sequences. The tracking step is achieved based on the initialized contour from segmentation using shape detection method.

2.1. Outline Detection using Hough Transform

In order to detect the outline of coronary artery, edge points in a given image are computed by gradient based filter first. And

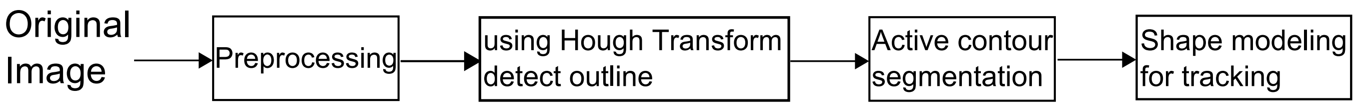

Fig. 1. An Overview of Proposed Method Workflow.

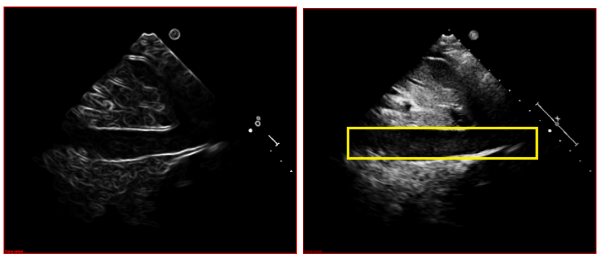

Fig. 2. Detection Result Using Hough Transform.

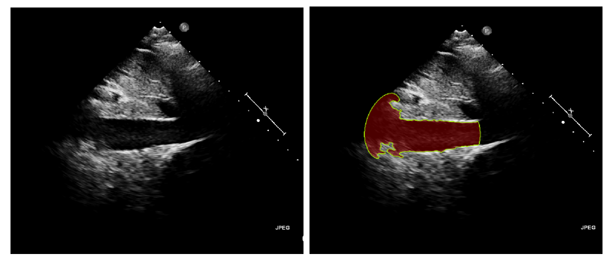

Fig. 3. Segmentation Result Using Active Contour.

then, the Hough Transform is applied to detect the outline [9]. Suppose that there is a line from (x_a, y_a) to (x_b, y_b) .We use Hough Transform to find distance from the origin and the angle of the line that go through the two points. The equation of the line can be written as

$$y = (\frac{\cos\theta}{\sin\theta})x + (\frac{r}{\sin\theta}) \tag{1}$$

Thus, the problem of detecting a line can be converted to the problem of finding the concurrent curves. Then the gradient operator is applied to calculate the magnitude image of the smoothing image. The output of the gradient operator produces a potential edge image of given image. After the preprocessing, Hough transform is applied to the edge image produced by gradient calculation. Hough transform converts the image to a parametric space and operating on a binary image of edge pixels, all possible curves $v(c, p_i) = 0$ through a pixel with vector coordinates c are transformed to a combination of parameters p_i , which then increment the corresponding cell of the accumulator array. Computations are performed for all edge pixels in the image, and the resulting accumulator array is searched for maxima to detect the curve with specific values of parameters.

In the process of detection of outline from coronary artery ultrasound image, two lines should be detected. In our case, the two lines with the maximal values in the accumulator array are considered the dominant lines of the coronary artery lumen. The detection process and result are shown in Figure 2.

2.2. Coronary artery segmentation

When the outline of coronary artery is detected the active contour is used to segment the accurate boundary of artery lumen. The segmentation is based on active contours which are energy-minimizing method guided by internal and external forces to propagate the contour to the boundary of interest. In our case, we propose that the role of force E_{int} is to enforce the active contour on a shape feature that is characteristic on the object. In the case of coronary artery, additional force that acts to preserve contour thickness should be added. To define such force, the initialized contour $f(s) = (x(s), y(s))$ and the first and second-order continuity weighting functions $\alpha(s)$ and $\beta(s)$ are used to obtain the internal energy function. This internal force can be used to avoid leaking in ultrasound image segmentation process. Internal force can be expressed as

$$\begin{aligned} E_{int} = \sum_i \alpha(i)||f(i+1) - f(i)||^2 \\ + \beta(i)||f(i+1) - 2f(i) + f(i-1)||^2 \end{aligned} \tag{2}$$

The contour is attracted to the edges with large image gradient under the image force in active contour framework. The image force is computed as

$$E_{img} = -(G_\delta * ||\nabla I||^2)(i, j) \tag{3}$$

Where I is the image intensity, G_δ is a two-dimensional Gaussian mask with standard deviation. In interactive application, a variety of user-places constraints force E_con can also be added. For our case the extern force is ignore for the purpose of designing a completely automatic tacking method. Then the coronary artery lumen can be segmented in the first frame of ultrasound image sequences as Fig.3 shown.

2.3. Coronary artery sequences tracking

In the next step, the shape modeling approach is used to force the initialized boundary moving closer to exact boundary of coronary artery. Shape modeling is based on the idea of level set to model propagating liquid interfaces with curvature-dependent speeds which is widely applied to image segmentation[10]. Then this propagation method continues tracking the boundaries in each frames boundary based on the

Fig. 4. Speed Image Generated By Equation 5

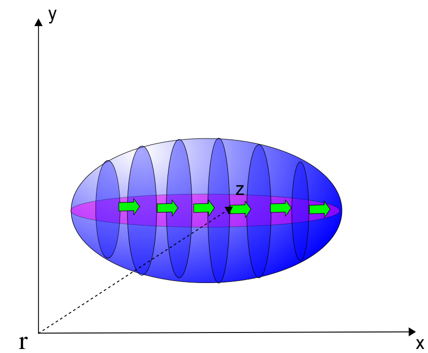

Fig. 5. The Spheroid Space Using to Constrain Evolution Space At Small Set of Points.

image gradient information. Shape modeling approach can be used to segment object's shape to situations where no shape prior available. The speed function will gradually attains zero speed as it gets closer to the object boundaries and eventually come to a stop when it reach to the exact boundary.

The accurate segmented result of first sequence is obtained for initialization of the shape modeling. The tracking process starts from the first frame of ultrasound sequences which is segmented using active contour. In the next frame, the initialized boundary starts to move close to the exact boundary of the coronary artery. Then this propagation method continues tracking the boundaries in each frames boundary based on the image gradient. We define the speed function F to be

$$F(x,y) = \frac{-F_A}{(M_1 - M_2)}|\nabla G_\sigma * I(x,y)| - M \qquad (4)$$

Where $M_1$and $M_2$are the maximum and minimum values of the magnitude of image gradient. This speed function can control the propagating front attaining zero speed as get to object boundary. If $F_G \neq 0$, then multiply the speed function with a term k that will cause the net speed of the front to approached to zero in the neighbourhood of a desire shape which is defined as

$$k_i(x,y) = \frac{1}{1 + e^{-|\frac{\nabla G_\sigma * I(x,y)}{\alpha}| - \beta}} \qquad (5)$$

Equation above has values that are close to zero in regions of high image gradient and values that are closer to unity in regions with relatively constant intensity. The speed image of one frame is shown as Fig 4.

In the tracking process, a spheroid space frame is proposed to update the exact boundary in each frames that the front can be moved by propagating the evolution function at a small set of points in the neighbourhood of the initialized contour instead of updating it at all points on the grid. In Fig.5, the spheroid depicts the tracking space and the evolution process only takes in this space. The spheroid space is bounded on a closed curve by a circle which has a radius of δ, that means, the artery boundary is tracked in the circle region with area $\pi\delta^2$. The initialized contour which lied inside moves until it collides with the boundary of the spheroid. And which boundary the front collides with depends on whether it is moving inward or outward. However, it cannot move outside the spheroid space. As a consequence of the spheroid space strategy, the initialized contour can be evolved through a maximum distance of . Using this tracking strategy, artery boundary of each frame is obtained by updating the segmented results from last frame.

3. RESULTS

Performance of the proposed algorithm is evaluated on 9 echocardiographic sequences with image size of $599 \times 799 \times 90$, each covering at least one complete cardiac cycle. The sequences are recorded using the *PHILIPS 5.0-MHz* transducer on the iE33 MATRIX Echocardiographic System. Manual segmentation is compared with the boundary outline generated by the proposed method using for the ultrasound sequences. Mean absolute distance (MAD) [11] is used to compare two contours. The MAD between two contours A and B is defined as

$$e(A,B) = \frac{1}{2}\{\frac{1}{n}\sum d(a_i, B) + \frac{1}{m}\sum d(b_i, A)\} \qquad (6)$$

where $A = \{a_1, a_2, ..., a_n\}, B = \{b_1, b_2, ..., b_n\}$ represent coordinates of points which define the respective contours and $d(a_i, B)$is the distance from point to the closet point on the contour B. The statistics of comparison experiments are presented in Table 1.The results show that 8 of 9 sequences can be tracked with mean below 2.5 and deviation below 0.5 respectively using Mean Absolute Distance measurement(MAD). Some inaccurate tracking is caused by low image quality. Tracking result of echocardiographic sequences is shown in Fig.5.

4. CONCLUSIONS

An automatic segmentation and tracking algorithm of coronary artery from ultrasound sequences is presented in this paper. The proposed approach combines both automatic seg-

Table 1. Results of The Comparison Between Manual Segmentation and Proposed Segmentation Method

	Sequence 1	Sequence 2
Distance between manual and proposed method(mean/deviation)	2.2026mm/0.395mm	2.025mm/0.402mm
Correlation Coefficient Between segmented areas(mean/deviation)	0.9905	0.9560

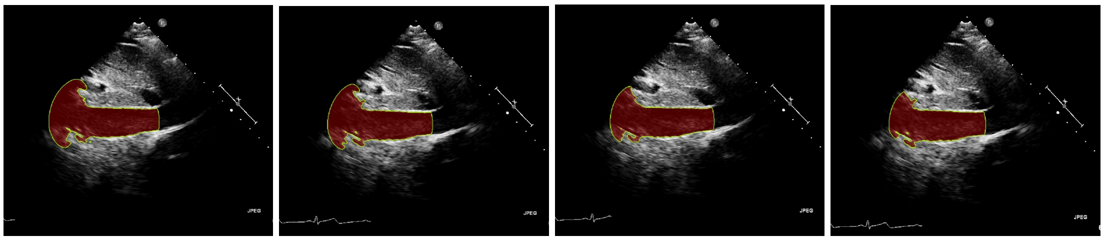

Fig. 6. Tracking Result of Coronary Artery From Echocardiographic Sequences In One Cardiac Cycle

mentation and tracking algorithm. Hough Transform is used for automatic detection of longitudinal coronary artery. In order to segment the exact boundary of the first image from sequences, active contour is used to generate an initialized contour of the coronary artery. To track the coronary artery movement in cardiac cycle, we propose a spheroid space frame in shape modeling to update the front of boundary in a specific region. The experiments show promising reslts of segmentation and tracking on different datasets.

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