Segmenting Echocardiography Images using B-Spline Snake and Active Ellipse Model

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Abstract — In this paper, a fully automated method for segmenting Left Ventricle (LV) in echocardiography images is proposed. A new method named active ellipse model is developed to automatically find the best ellipse inside the LV chamber without intervention of any specialist. A modified B-Spline Snake algorithm is used to segment the LV chamber in which the initial contour is formed by the predefined ellipse. As a result of using active ellipse model, the segmentation is extricated from dealing with gaps within myocardium boundary which are highly problematic in echocardiography image segmentation. Based on the results obtained from different studies, the proposed method is faster and more accurate than previous approaches. Our method is evaluated on 20 sets of echocardiography images of patients; and acquired results (92.30±4.45% dice's coefficient) indicate the proposed method has remarkable performance.

Index Terms — B-Spline Snake, Active Ellipse Model, Apical Four Chamber Images.

I. INTRODUCTION

Echocardiography is a valuable non-invasive method extensively used in clinical cardiology. Several clinically important parameters such as cardiac chamber size, wall thickness, cardiac output, ejection fraction and left ventricular mass can be derived from echo images. Among all important features, the segmentation of the Left Ventricle chamber has been widely investigated by researchers. Numerous efforts such as Markovian random fields [1, 2], and active contours [3-5] have been widely used in order to segment echocardiography images. Among several available approaches, active contours, is commonly utilized in segmentation of medical images [6]. Conventional active contour methods, Snake, typically suffer from slow convergence speed due to large number of coefficients to be optimized. An alternative approach is B-Spline Snake, which has built-in smoothness requirement, and hence provides faster convergence [7, 8]. The disadvantage of almost previous approaches is that they suffer from the lack of a confident way to specify the initial contour.

So, the specialist intervention has been required to specify some points inside the LV. If the initial contour is selected far from proper boundary, the segmentation method should utilize balloon force [9] or Gradient Vector Flow (GVF) force with higher iterations to guide the contour toward the myocardium boundaries. If the balloon force is utilized, the gaps within myocardium boundaries become highly problematic and the contour is prone to exceed the proper boundary. On the other side, if the GVF force is utilized, the computational time will tremendously increase.

Some attempts have been made to automatically find the LV chamber inside the apical images by using morphological operands to estimate the center point of LV [10].

In this paper, a novel approach to define the best initial contour, Active Ellipse Model, is proposed which eliminates the need of human intervention and offers a full-automatic method to segment left ventricle chamber. At first, an intersection point (IP) of four chambers is sought inside apical four chamber images. Afterward, a small ellipse is positioned at the top and left side of the IP. During the evolitional process, the interaction of internal and external forces pushes the ellipse toward the myocardium boundary. Finally, the best ellipse inside the LV chamber is defined.

This method offers at least two major advantages over previous method which utilizes morphological process by: 1) Eliminating massive computations due to removing mathematics of morphological operands. 2) Achieving enhanced accuracy as active ellipse model is much more robust than morphological operands against destructive effect of large gaps that exist typically on endocardium. After finding the best fitness of the ellipse inside the LV chamber, the ellipse will be used to form the initial contour of B-Spline Snake. Thus, the initial contour is placed close to the proper boundary and the GVF force is no longer needed to be used. Therefore, the proposed method is remarkably faster than previous approaches [8].

This paper is categorized into four sections as follows. In section II we discuss the details of our methodologies. The acquired results are presented in section III. The conclusions and a brief perspective of our approach are provided in section IV.

II. METHOD DESCRIPTION

In this section, an algorithm for detection of endocardial boundary in echocardiographic images is developed.

A. Active Ellipse Model

Active ellipse model is developed to locate LV chamber in apical chamber views. At first, the Intersection point of chambers inside A4C (Apical 4 Chambers) view is detected. Then, a small ellipse placed on top-left side of the IP. The ellipse grows among iterations to fit the chamber. Internal force and external force are utilized to control the evolution of the ellipse. The former is defined to support the growing of the ellipse and the latter bounds it with the boundary of the LV. An ellipse is defined as
\( e(k, x_i, y_i, r_i, r_j) = [x(k, x_i, r_i, r_j), y(k, y_i, r_i, r_j)], k = 1, ..., N \).

\[
x'(k, x_i', r_i') = x_0' + r_0' \cos(\theta_k) \tag{1}
\]

\[
y'(k, y_i', r_i') = y_0' + r_0' \sin(\theta_k) \tag{2}
\]

where \( i \) shows the iteration of computations, \([x_i, y_i]\) is the center of ellipse, \([r_i, r_j]\) defines radiuses of ellipse in vertical and horizontal direction and \( \theta_k \) is the angle between the \( k^{th} \) point of ellipse and the vertical axis (Fig. 1).

Fig. 1. Depiction of ellipse model used in proposed method

\[
\begin{bmatrix}
\Delta x' \\
\Delta y' \\
\Delta x'' \\
\Delta y'' \\
\end{bmatrix} =
\begin{bmatrix}
\alpha & -\alpha & 0 & 0 \\
\alpha & -\alpha & 0 & 0 \\
\alpha & 0 & 0 & 1 \\
0 & \alpha & 0 & 1 \\
\end{bmatrix} \begin{bmatrix}
f_{x'} \\
f_{y'} \\
f_{x''} \\
f_{y''} \\
\end{bmatrix}
\tag{3}
\]

Where, \([\Delta x', \Delta y']\) is the translation vector of the center point and \([\Delta x'', \Delta y'']\) is the modification vector of the radiuses of iteration \((i+1)^{th}\). \( f_{x'} \) and \( f_{y'} \) are vertical components of the external force. The plus and minus signs of these components refer to their directions. \( f_{x''} \) and \( f_{y''} \) are horizontal components of the external force. The coefficient \( \alpha \) controls the influence of external forces on the evolution of the ellipse. \( \beta \) is the constant speed of ellipse evolution. The summation of \( \Delta x', \Delta y', \Delta x'', \Delta y'' \) is calculated for each iteration and the process will be completed when the summation becomes lower than 0.01.

B. Internal and External Forces

The evolution of ellipse is determined with interaction of internal and external forces. The internal force brings the ability of growing while the external force plays the key role to fit the ellipse inside chambers. The external force is constituted of 4 forces as illustrated in Fig 2. These components are obtained with equations (4)-(5).

\[
f_{x'} = \sum_{i=1}^{N} \exp(-E'(x_i') - \mu_{myo})^2 / \sigma_{myo} \times W_{x'}(i) \times \frac{k}{N} \tag{4}
\]

\[
f_{y'} = \sum_{i=1}^{N} \exp(-E'(y_i') - \mu_{myo})^2 / \sigma_{myo} \times W_{y'}(i) \times \frac{k}{N}
\]

\[
f_{x''} = \sum_{i=1}^{N} \exp(-E'(x_i') - \mu_{myo})^2 / \sigma_{myo} \times W_{x''}(i) \times \frac{k}{N}
\]

\[
f_{y''} = \sum_{i=1}^{N} \exp(-E'(y_i') - \mu_{myo})^2 / \sigma_{myo} \times W_{y''}(i) \times \frac{k}{N}
\]

and,

\[
W_{x'}(i) = \begin{cases} 
\cos(2\pi t) & \text{if } \frac{1}{4} \leq t \leq \frac{3}{4} \\
0 & \text{otherwise}
\end{cases} \tag{5}
\]

\[
W_{y'}(i) = \begin{cases} 
-\cos(2\pi t) & \text{if } \frac{3}{4} \leq t \leq \frac{1}{4} \\
0 & \text{otherwise}
\end{cases}
\]

\[
W_{x''}(i) = \begin{cases} 
\sin(2\pi t) & \text{if } \frac{1}{2} \leq t \leq 0 \\
0 & \text{otherwise}
\end{cases}
\]

\[
W_{y''}(i) = \begin{cases} 
-\sin(2\pi t) & \text{if } 1 \leq t \geq \frac{1}{2} \\
0 & \text{otherwise}
\end{cases}
\]

where \( i \) is the iteration. Parameters \( \mu_{myo} \) and \( \sigma_{myo} \) represent the estimated mean and variance of the myocardium intensity and are calculated with maximum likelihood formulations [11]. The Fig 3 shows the evolution of the ellipse in some iteration.

C. Finding Initial Ellipses

First, the intersection point of chambers is determined and afterward, the initial ellipse is placed inside the LV chamber. According to the experiments, the intersection point is placed near the mass center of the LV in the image. Therefore, the mass center, \( P_{mc} \), is calculated. Then, another window is selected centered at \( P_{mc} \) and the mass center of it is calculated again. The result is considered as the intersection point. Now, the initial ellipse (iteration #1) is placed on upper-left side of the intersection point. Radiuses of initial ellipse are selected equal 5 points; however, changing these radiuses have an unnoticeable effect on the performance of the method.

D. New Active B-Spline Contour

In B-Spline snake, the contour is represented by B-Spline basis functions and few control points govern the deformation of the contour in interaction with image forces [8]. Cubic B-Spline snake offers a reasonable comprise between the complexity of the algorithm and the ability to
fit in to arbitrary boundaries. Cubic B-Spline snake is characterized by \( N \) control points \( Q = \{x_i, y_i\}, i = 1, \ldots, N \) and \( N \) connected curve segments \( g_i(s) = [u_i(s), v_i(s)] \) where \( 0 \leq s < 1 \). Each curve segment is a linear combination of four cubic polynomials in \( s \).

\[
g_i(s) = [s^3 \ s^2 \ s \ 1] \cdot M \cdot \left[ Q_{\lfloor (i-1) \mod N \rfloor} \ Q_{\lfloor (i+1) \mod N \rfloor} \ Q_{\lfloor (i+2) \mod N \rfloor} \right], i = 1, \ldots, N
\]

where,

\[
M = \begin{bmatrix}
-1/6 & 1/2 & -1/2 & 1/6 \\
1/2 & -1 & 1/2 & 0 \\
-1/2 & -1 & 1/2 & 0 \\
1/6 & 2/3 & 1/6 & 0
\end{bmatrix}
\]

By setting \( s = 0 \) in (1), we obtain so-called node points \( P_i, i = 1, \ldots, N \), which are located on the contour and are related to the control points as follows.

\[
P = A \cdot Q
\]

\[
A = \begin{bmatrix}
1/6 & 2/3 & 1/6 & 0 & \ldots & 0 \\
0 & 1/6 & 2/3 & 1/6 & 0 & \ldots & 0 \\
& \ddots & \ddots & \ddots & \ddots & \ddots & \ddots \\
0 & \ldots & 0 & 1/6 & 2/3 & 1/6 & 0 \\
1/6 & 0 & \ldots & \ldots & 0 & 1/6 & 2/3 \\
2/3 & 1/6 & 0 & \ldots & \ldots & 0 & 1/6 \\
\end{bmatrix}
\]

where \( p, Q \in \mathbb{R}^{N \times 2} \) and \( A \in \mathbb{R}^{N \times N} \). Node points offer a more tangible representation of B-Spline snakes.

### E. Initial Contour

As discussed in section A, the fitted ellipse inside the LV is used to form the initial B-Spline contour. Therefore, node points are aligned evenly on the ellipse. The angle between two consecutive node points controls the smoothness or the accuracy of the detected boundary. If the angle is selected low, the accuracy of the contour increases but, makes the computational time longer. A proper selection of this angle leads to attain a good tradeoff between smoothness and accuracy.

As asserted previously, the active ellipse model is robust against gaps through myocardium boundary. The B-Spline contour will hold this characteristic, provided that no node point is placed on the initial contour in front of gaps. To maintain this rule, perpendicular lines to the initial contour starting at potential node points is considered which samples are taken over them. The intensity of samples over a specific perpendicular line determines whether the related potential node point is placed in front of gap area (Figure 4).

### F. Contour Evolution Equations

In order to calculate the displacement of node points at each iteration, a balloon force vector, \( \vec{B} \), is defined for node points which gradually push the contour outward. A stopping factor, also, is defined to cease the contour when the contour approaches the adjacent of boundary. In fact, the stopping factor reduces the balloon force related to the node point which meets the adjacent of the boundary and the specific node point gradually stops from further moving.

Clearly, at \( t \) th iteration, stopping factor of each node point is mainly influenced by intensity of pixels on its two neighboring curve segments, i.e. \( g_i \) and \( g_{i-1} \). More specifically, suppose each curve segment \( g_i \) is sampled at \( M \) points. Suppose, also, that intensity at each point on the contour is saved in \( F \in \mathbb{R}_{N \times 2} \). Now, to calculate the stopping factor of each node point \( P_n \), we first transmit the intensities on \( g_i \) and \( g_{i-1} \) to \( P_n \). This is performed using a weighted sum of \( F \), which aims to weigh the contribution of sample points close to \( P_n \) as is summarized below.

\[
\vec{F}(t) = D \cdot \vec{F}(t)
\]

\[
D = \begin{bmatrix}
b_1^T & 0 & \ldots & b_N^T \\
0 & b_1^T & 0 & \ldots & 0 \\
& \ddots & \ddots & \ddots & \ddots & \ddots & \ddots \\
0 & \ldots & 0 & b_N^T & 0 \\
0 & \ldots & 0 & 0 & b_N^T
\end{bmatrix}
\]

and,

\[
b(m) = \begin{cases}
m - 1 \over M & m = 1, \ldots, M \\
2 - m - 1 \over M & m = M + 1, \ldots, 2M + 1
\end{cases}
\]

\[
b_i(m) = 1 - b(m) \quad \text{and} \quad b_i(m) = b(m), \quad m = 1, \ldots, M
\]

where \( n \in \mathbb{R}_{N \times 2} \) contain the stopping factor on node points \( P_n \). Thus, the balloon force is modified in iterations according to the following equation.

\[
\vec{B} = \vec{B}_i - \lambda \times \vec{F}(t)
\]

where \( \vec{B} \) and \( \vec{B}_i \) are Balloon force vectors of iterations \( i \) and \( i - 1 \), respectively. Now, displacement of each node is determined in proportion to the balloon force on the corresponding node:

\[
\Delta \vec{P} = \vec{B}_i
\]

Hence, displacement of control points is determined as:

\[
\Delta Q_i = A^{-1} \Delta P_i
\]

**Fig 4.** The figure shows initial contour creation. Red points are selected node points and yellow points show eliminated points. Perpendicular lines are shown with gray lines.

### III. EXPERIMENTS AND RESULTS

The proposed method is implemented in MATLAB7.7 environment using a PC with 2.2 GHz Core 2 Duo Processor and 3 GB of Memory. In addition, Images are acquired with a Pinnacle capture card from a VIVID3 echocardiography instrument (made by General Electric Healthcare). According to examinations, the table 1 shows the best
The innovation behind implementing the active ellipse model makes our method to be highly reliable for echocardiography images which commonly have large gaps among myocardium walls. Moreover, the iterations of B-Spline method are significantly reduced due to the fact that the initial contour is positioned at the adjacent of actual boundary. As a result, the implementation of GVF is no longer needed which is proven to have a high computational cost. Furthermore, the intervention of specialist is eliminated and consequently, the method becomes fully automated for boundary detection in apical views of echocardiography images.

Potentially, this method can be implemented for 3D echocardiography images which are available in newly developed echocardiography instruments.

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REFERENCES