Contouring Left Ventricle
From Echocardiographic Image Sequence In Long-Axis View

Anastasia Bobkova, Sergey Porshnev, Vasiliy Zuzin
Institute of radio engineering, Ural Federal University of the First President of Russia B.N. Yeltsin
Ekaterinburg, Russia

ABSTRACT

In this paper we suggest an approach to a completely automatic contouring the left ventricle (LV). We use the method of signatures to describe the shape of the contour. Analysis of contours performed manually enables us to conclude that the signature of any contour of any patient has the shape of the inverted letter "*M*".

This allows reducing the contouring problem to the problem of signature reconstruction. So, the task is transferred from a two-dimensional space in a one-dimensional. Algorithm of semi-automatic contouring based on the known first frame contours is described. So, it is obvious that the problem of completely automatic contouring demands to select the contour on the first frame automatically. Solution of this problem is to restore the signature with the correct shape in the form of the inverted letter "*M*" and we offer a way to do it.

Keywords: left ventricle, contouring, automatic contouring, signature, echocardiography.

1. INTRODUCTION

Echocardiography has several advantages over other medical imaging techniques. It is noninvasive, it does not produce ionizing radiation, and it is relatively nonexpensive and fairly simple to use. For this reason it is widely used in cardiology as well as other medical applications. The problem of automatic identification of the boundary of the heart ventricles on the basis of echocardiographic images has received considerable attention in the literature. It is aimed to provide computational and display tools for the diagnosis of heart disease. The apical four-chamber position is one of the key in the study of global and local contractility of the LV (also called long-axis LV apical view). In this study, we are interested in automatic contouring of LV in this position. Samples of the echocardiogram images and user defined contour are presented on Fig. 1.

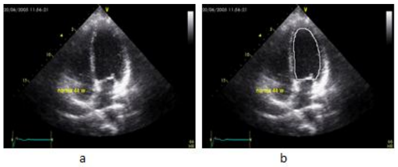

Fig. 1. Echocardiogram image (a) and user defined contour (b)

The major automatic contouring approaches use interpolation of edge pixels [1], snakes [2], segmentation based on Markov Random Fields [3], and Optical Flow [4]. Nevertheless, these techniques in echocardiogram images suffer mainly from usual poor quality of images. Moreover, they are computationally intensive [5]. In [5], a technique using constrained tracking has been proposed. The major drawback of this method is that the set of parameters used are to be tuned by the cardiologist.

In [6], an automated method of LV boundary detection in long-axis view is proposed. The method uses a watershed transform and morphological operation to locate the region containing the LV and then performs snake deformation with a multiscale directional edge map for the detection of the endocardial boundary of the LV. Boundary detection results is presented in Fig. 2. Figures show that shape of automatically found contour does not correspond to one defined by the user.

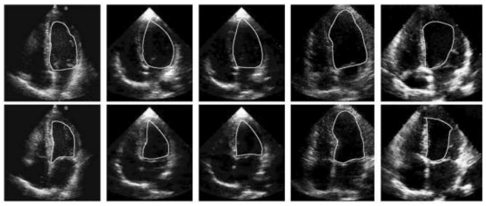

Fig. 2. LV boundary detection results in end-diastole frames (first row) and end-systole frames (second row) from [6]

The analysis of works on the LV delineation in long-axis view leads to the conclusion that the form of the allocated areas is far from the correct LV shape. In this paper method of signatures is applied to describe contour shape and this allows reducing the contouring problem to the problem of signature reconstruction. The paper is organized as follows. In Section 2, we analyze user defined contour applying the signature approach. Algorithm for semi-automatic contouring is presented in Section 3. Issues related to the completely automatic contouring are discussed in Section 3.

2. ANALYSIS OF USER DEFINED CONTOUR

Contour shape may be described by method of signatures. Signature is a description of an object boundary using *1D* function. One of the simplest methods for signature construction is to find the dependence of the distance from the centroid to the user defined contour as a function of the angle. Such signature is presented in Fig. 3.

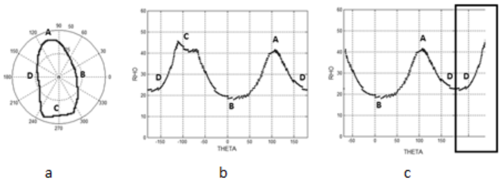

Fig. 3. User defined contour in polar coordinates (a), contour signature (b) and modified signature (c)

Compare the signatures and contour plots in polar coordinates. The lower bound of contour (Fig. 3, section C) is constructed as a straight line connecting the lowest points. If necessary, it is easy to recover, so we exclude it from the contour signature. The left bound of contour (Fig. 3, section D) is unbreakable. Therefore, it's necessary to move the points of the left border in order to ensure the correctness of the border construction. Moved part of the signature is highlighted by rectangle in Fig. 3. Modified signature has the form of the reversed letter «*M*».

The task of automatic contouring is reduced to the restoration of this modified signature on the basis of the automatically computed boundary points.

Next, we examine the semi-automatic contouring and methods for complete automation of this process.

3. SEMI-AUTOMATIC CONTOUR DETECTION

Algorithm for semi-automatic allocation of boundary points is based on the user defined contours for end-systole and end-diastole as a priori information. It is implemented by the following sequence of actions:

1. For every initial image:
    1.1. Read initial image $I(i,j)$ with $FRAME$ number;
    1.2. Transform $I(i,j)$ to gray level image $I\_gray(i,j)$;
    1.3. Resize $I\_gray(i,j)$ to uniform image size;
    1.4. Cut out LV region fragment. Resulting image of this step is $I\_croped(i,j)$;
    1.5. Reduce to 9 times;
    1.6. Record to $I\_gray(i,j,FRAME)$ array.
2. Calculate boundary regions for every image in $I\_gray(i,j,FRAME)$ array:
    2.1. Reduce to the size of $I\_croped(i,j)$ image (see step 1.4) using bilinear interpolation;
    2.2. Apply thresholding (threshold is 70 for the image intensity range from 0 to 255);
    2.3. Perform connected component labeling;
    2.4. Calculate area of each component;
    2.5. Keep regions, which area is over accepted value ($S_{lim} = 300$). Resulting image of this step is $Region(i,j)^{FRAME}$;
    2.6. Use a priori information to calculate the map of possible location of contours for given patient:
        2.6.1. Read user defined contour for the first frame;
        2.6.2. Resize it to uniform image size;
        2.6.3. Cut out LV region fragment;
        2.6.4. Apply dilation operation with square structuring element (width of 3 pixels);
        2.6.5. Apply black regions filling operation on white background;

Result of this step is the binary mask ($BW(i,j)$) determining possible the position of contours for the given patient.

    2.7. Reorganization of binary images $BW\_region(i,j)^{FRAME}$ (see step 2.5) with the purpose to obtain boundary regions:
        2.7.1. If $FRAME = 1$ or $FRAME = s$ or $FRAME = Fn$ (s – end-systole frame number), then $BW\_region(i,j)^{FRAME}$ is user defined contour. These 3 contours are contours of support. The support contours can be used to refine the intermediate contours, since the deformation of the left ventricle is consistent.
        2.7.2. In all other cases:
            – $BW\_region(i,j)^{FRAME} = 0$, if $BW(i,j) = 0$ (e.g. keep parts of regions that correspond to possible contours position for the given patient).
            – $BW\_region(i,j)^{FRAME} = 1$, if $BW\_region(i,j)^{1} = 1$ (e.g. set limitation for more accurate contour construction).

For certain patients, some parts of the LV boundary may be unclear on echocardiogram image. This can lead to inaccurate approximation of the contour signature, since there are no enough points in these parts to build a true signature. In such cases, an expert completes the border based on the representation of an ideal contour. We overlay the contour of the first frame in order to ensure that each boundary part has a sufficient number of points. The internal pixels of these regions should be used to approximate the contour signature.

3. Keep pixels of internal boundary of $BW\_region(i,j)^{FRAME}$:
    3.1. Find coordinates of all nonzero pixels in $BW\_region(i,j)^{FRAME}$ (in Cartesian coordinates);
    3.2. Calculate step for shifting the origin of coordinates to the point in end-systole contour center.
    3.3. Shift origin of coordinates to the center of end-systole;
    3.4. Transform coordinates of all nonzero pixels to polar coordinates (*THETA* and *RHO*).
    3.5. Calculate position of the internal pixels. Divide $[THETA_{min}, THETA_{max}]$ interval into N parts and find minimum value of RHO for each part.

Obtained values RHO_r and $THETA_r$ define points for contour signature approximation ($r = \overline{1,R}$, R is amount of obtained internal points). Approximation of contour signature is implemented by the following sequence of actions:

1. Read points with RHO_r and $THETA_r$ coordinates;
2. Delete points with $-100 < THETA_r < 50$;
3. Shift points with $THETA_r < -100$ to the right on value s_r: $s_r = 180 + (180 - |THETA_r|) = 360 - |THETA_r|$;
4. Approximate by polynomial of order 9 and obtain the dependence $THETA(RHO)$;

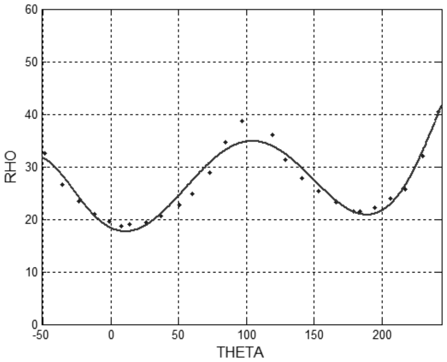

Fig. 4. Approximation of modified signature by polynomial of the ninth degree

Result of modified signature approximation by ninth degree polynomial is presented in Fig. 4.

Then the inverse transformation must be performed to pass from representation of the contour in the form of the modified signature ($THETA(RHO)$) to the representation as a binary image.

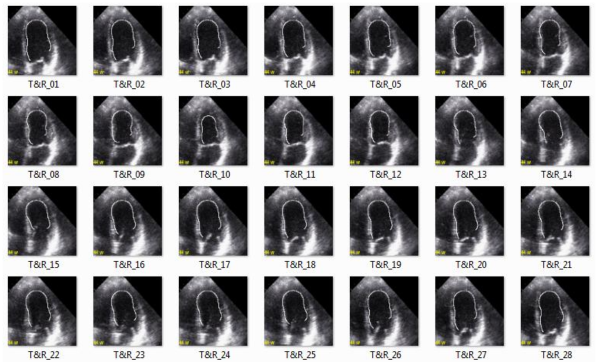

Fig. 5. Result of semi-automatic contouring

Results of semi-automatic contouring for a patient are presented in Fig. 5. The figure shows that the obtained contours are quite believable. The figure shows that the shape of the contour corresponds to the user defined contour shape. Thus, semi-automatic contouring gives results that are quite similar to the results of an expert, but the contours in end-systole and end-diastole are used as a priori information. It is necessary to exclude this information in an automated version of the contouring.

4. AUTOMATIC CONTOUR DETECTION

The basic automatic contouring approach remains the same. The difference is that contour on the first frame is calculated automatically and then is used just like the user defined contour for the first frame in the semi-automatic mode. In addition, shifting the origin of coordinates to the point in end-systole is replaced by shifting to center of selected binary boundary image.

Thus, the problem of completely automatic contouring is reduced to the automatic selection of the contour in the first frame. So, it is especially important to find the correct contour on the first frame automatically. To do this correct modified signature of the first contour must be constructed. It should be like an inverted letter "*M*". Let us consider the steps that were used in this study to construct a correct first contour signature.

4.1. Generalized Contour

The contour of each patient has individual characteristics, but all contours have a similar shape. So, we can specify a generalized form of LV contour as a binary mask defining a region of possible contours: $MAP = \sum_{i=1}^{P} true_i^1$, P is amount of patients, $true^1$ is the user defined contour of the first frame.

Using morphological operations of dilation, erosion, and hole filling, we obtain a binary mask. Then the Sobel method is used to detect the binary mask edge. This is generalized contour (Fig. 6(c)).

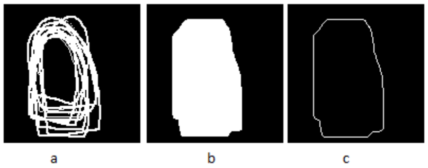

Fig. 6. Binary mask (b) and generalized contour for all patients (c)

This contour is used in the procedure for selection points for signature construction.

4.2. Procedure For Boundary Region Selection

The procedure for selection of the boundary region for the first frame is slightly different:

1. Increase the image of 9 times (Fig. 7(a)).
2. Adjust the image intensity inhomogeneity by calculating of morphological opening and then subtracting it from the original image (Fig. 7(b)).
3. Apply thresholding (threshold is 20 for the image intensity range from 0 to 255) (Fig. 7(c)).
4. Remove small white areas on a dark background (Fig. 7(d)). Little region is such one, whose area is less, or equal to the pixel P ($P = 300$).
5. Keep only those pixels that correspond to the non-zero pixels in the binary image MAP.
6. Overlay the generalized contour onto resulting binary image (fig. 7(e)).

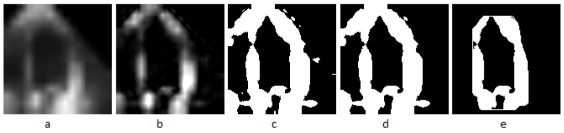

Fig. 7. Selection of binary boundary image for the first frame

Then we keep pixels of internal boundary of this region as well as in the semi-automatic mode. Obtained pixels define points for contour signature approximation.

4.3. Contour Signature Construction

In some cases, the points that were automatically found to approximate the modified signatures are invalid. This is especially noticeable in the left and right sides of the modified signature. Therefore, the approximation of modified signature does not give good results. The resulting signature is not similar to an inverted "*M*".

Figure 3 shows that the modified signature can be divided into two parts that are easy to describe by the second-degree polynomial. This provides assurance that the sides of the curve will go up in any case. Afterwards interpolation is used to construct a modified signature from the results of approximation of the left and right sections.

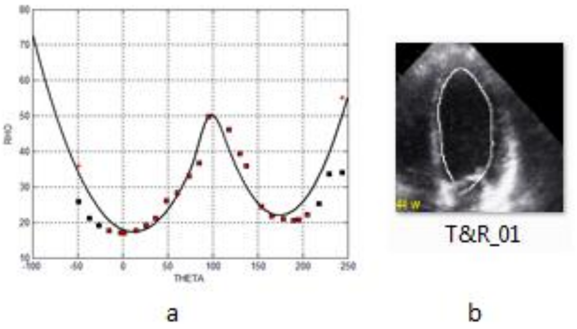

Fig. 8. Result of modified signature approximation (a) and resulting contour for the first frame (b)

Illustration of the modified signature approximation result for the first frame is shown in Fig. 8, resulting contour for the first frame is presented in Fig. 8.

Thus, having constructed the automatic contour on the first frame, we can use it in the above described algorithm for semi-automatic contouring. So, contouring becomes completely automatic.

5. CONCLUSIONS

In this paper we analyzed the possibility of semi-automatic and automatic contouring of the left ventricle. Tests have been performed on echocardiographic images of twelve patients. All patients belong to the group without pathologies.

Algorithm of semi-automatic mode is described. The result of contouring in this mode is similar to the expert result. Problem of completely automatic contouring is reduced to the automatic selection of the contour in the first frame, while the basic approach to solving remains the same. Application of the completely automatic contouring approach to the first frame of different patients gives quite good results. We can therefore conclude that our idea for a completely automatic contouring is effectual.

Further study is required for refining the position of the lower points of the left and right borders of the contour. In addition, it is advisable to refine the contours using the fact that the changes of contours shape are strictly consistent from frame to frame. This is a possible direction for further research.

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