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# Enhanced Endocardial Boundary Detection in Echocardiography Images using B-Spline and Statistical Method

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Extraction of endocardial motion is important to provide more accurate myocardial motion for further cardiac image analysis. This process involves endocardial detection which is challenging due to the presence of speckle noise and discontinuities of endocardial boundary. Researchers actively investigate various approaches to perform endocardial detection even though they involve extensive computations task and time consuming. In this paper, we implement a basic edge map detection using gradient and cavity-center-based method to detect the endocardial boundary. This method produces a boundary which still has discontinuities and outlier coordinates. To enhance the boundary, we propose a method based on a B-Spline and statistical approach to remove the discontinous points along the endocardium on parasternal short axis view of cardiac. The proposed method produces results which give visual evidences that it is able to significantly enhance the endocardial boundary.

**Keywords:** Endocardial boundary, Discontinuity, B-Spline, Statistical method, Echocardiography images

## 1. INTRODUCTION

Detection of endocardial boundary is an important task in analyzing myocardial functions for cardiac abnormality diagnosis. Using detected endocardial boundary, physicians could observe the endocardial motion, the cavity volume and the ejection fraction between end-diastole and end-systole, etc. Even though researchers actively investigate this area, it still remains difficulties to obtain an accurate endocardial boundary due to the presence of speckle noise and discontinuities of the boundary on echocardiography images.

Difficulties and, at the same time, opportunities of the endocardial boundary detection attract researchers to propose various detection approaches. The pioneer approach is the active contour model or snakes which then became a basis for other methods such as the gradient vector flow and its derivation[1-3].

This approach is performed by minimizing the potential energy of edge along the boundary. Some modifications on the snake model and its optimization algorithm have been done and implemented on the segmentation task of echocardiography images[4]. The snake method is also written as a popular approach for endocardial boundary detection. Even though the method is widely used, it remains a problem in term of computation time that may not suitable for real time applications.

Nowadays, researchers also implement multi-scale based method for edge detection task as the edge is also multi-scale in nature. A well-known initial work of multi-scale method for edge detection was introduced in[5]. For natural images data set, a combination of strengths of cues from the large-scale and small-scale is successfully improve the edge detection until 50% over the single-

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scale approaches[6]. An improvement on how to combine different scale cues has been proposed based on a statistical approach using joint probability distribution[7]. Subject to evaluation criteria used, the proposed approach outperforms other methods and significantly optimizes the combining task. Generally, the multi-scale approaches produce promising results in endocardial boundary detection with their ability to extract edge's cues from different scales. However, these approaches is also time consuming and involves extensive computation tasks.

Motivated by the study which is discussed above, we aim to develop a simple but effective approach to automatically detect the endocardial boundary. Our approach begins with the computation of edge map based on gradient and cavity-center approach to find out the endocadial boundary. We then enhance the boundary by identifying the discontinuities using a statistical approach and connect the respective points using a B-Spline method.

## 2. METHODOLOGY

The proposed method for enhancing the detection of endocardial motion involves several steps. They begin with a speckle reduction task using the QGDCT filtering technique[8] and then continue with optical flow computation as previously published in[9] which results flow vectors for all pixels of image. For the detection of endocardial boundary, we implement three steps, i.e. computation of boundary points involving gradient and cavity-center approach; identification and removal outlier points using statistical method; and reconnect the points using B-Spline. After the smooth boundary is obtained, the endocardial motion is extracted from along the boundary points. As the speckle reduction and computation of optical flow have been previously published, in this section, we only discuss the three steps for the detection of endocardial boundary.

### *A. Detection of endocardial boundary*

Detection of endocardial boundary is performed using edge map computation techniques and a cavity-center-based approach. Several edge detection techniques, i.e. Sobel, Prewitt, Roberts and Canny, have been implemented to obtain edge maps all over the image. We then visually evaluate the results to determine the best edge map among them.

Edge map provides edges of different intensity on all locations of image. Since we only need the endocardial boundary, the edge along endocardium is then extracted from the Canny image. To perform this extraction task, we consider the cavity center which is previously selected as a reference point. We implement an extraction technique based on the cavity center and row-column approach detailed in the pseudo codes shown in Fig. 1.

```
Read the Canny image
Select a cavity center (r_c, c_c)
For row r_c:
   Find out the edge on the right and left side
   of the caity center
   Record the coordinates obtained
Repeat the above procedures for any rows on the
 up and below the cavity center
```

Figure 1. Pseudo codes of the proposed algorithm to extract endocardial boundary coordinates from the Canny image

### *B. Identification and removal outlier points*

Endocardial boundary obtained from the edge map is a good initial result. However, the boundary often has discontinuities due to improper image acquisition. The discontinuities are represented by outliers of the boundary coordinates. Therefore, we extract the boundary coordinates and then identify the outliers by considering the interquartile range (*IQR*) approach, which is defined as

$$IQR = Q_3 - Q_1 \qquad (1)$$

where $Q_1$ and $Q_3$ are the upper and lower quartiles of the coordinates data, respectively. The outlier data are defined as any data outside a range

$$[Q_1 - k(Q_3 - Q_1), Q_3 + k(Q_3 - Q_1)] \qquad (2)$$

where $k$ is a constant. Once identified, the outliers are then removed from the coordinate's data set.

### *C. Reconnect points*

The removal of outlier data remains discontinuities between two or more coordinate points. To reconnect them, we implement a B-Spline method to generate continuous endocardial curves. In this research, we select de-Boor algorithm, which is one of a stable and robust B-Spline method.

Let a $p$ number of points are selected along the curve with coordinates

$$[(a_0,b_0),(a_1,b_1),(a_2,b_2),...,(a_{p-1},b_{p-1})] \qquad (3)$$

The de-Boor algorithm will find a curve $s(x)$ for every point $x \in \left[a_0, a_{p-1}\right]$. Assume that $x \in \left[a_l, a_{l+1}\right]$ for $l$ is a pivot point, $0 \le l \le p-1$, and $b_i^{[0]} = b_i$ for $i$ = $l$-$n$, …,$l$ where n is polynomial degree, the de-Boor algorithm computes

$$b_i^{[k]} = (1 - a_{k,i})b_{i-1}^{[k-1]} + a_{k,i}.b_i^{[k-1]} \qquad (4)$$

where $k$ = 1, …, $n$ and

$$a_{k,i} = \frac{x - a_i}{a_{i+n+1-k} - a_i} \qquad (5)$$

Finally, points along the curve are found out by

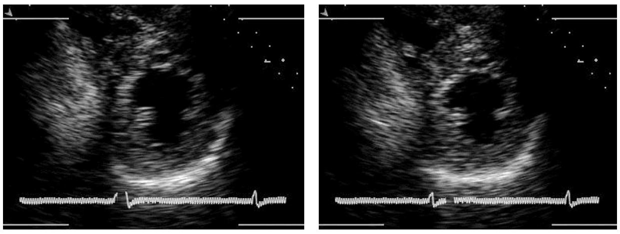
$$s(x) = b_i^{[n]} \qquad (6)$$

## 3. RESULTS AND DISCUSSION

### *A. Computed Optical Flow*

The proposed method has been implemented on clinical echocardiography data which are recorded by physician on PSAX view using a Siemens Acuson Sequoia scanner. In this paper, for instance we use two consecutive frames of cardiac motion during systole which are 1st frame and 2nd frame as shown in Fig. 2(a) and (b) respectively. The computed optical flow from these two frames and its zoomed in view are shown in Fig. 3(a) and (b) respectively.

Optical flow technique used to detect cardiac motion produces flow vectors on every pixel of the image. If we observe the flow vectors on the image shown in Fig. 3(b), the endocardial boundary has correct and smooth arrows while vectors inside myocardium look have more errors in their direction due to the presence of speckle noise. Therefore, in order to accurately compute the endocardial motion, we need only consider extracting vectors along the boundary, instead of all flow vectors on the myocardium. Shortly, this figure confirms that flow vectors along endocardial boundary are smoother than inside myocardium and appropriate for further process.



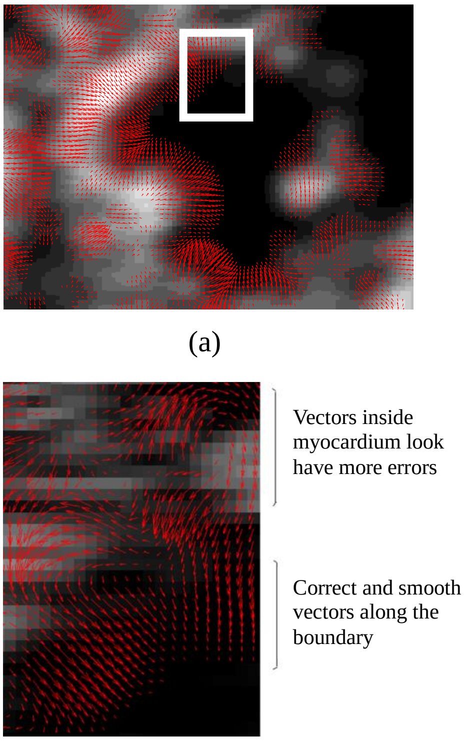
(a) (b)

Figure 2. Example of two consecutive frames during cardiac systole (a) 1st frame; (b) 2nd frame

### *B. Detected Endocardial Boundary*

The results of edge detection using gradient and cavity-center method are shown in Fig. 4. By observing visually, this figure shows that the Canny detection produces more complete boundary than other techniques. Thus, Canny edge map is more suitable used to obtain the endocardial boundary.

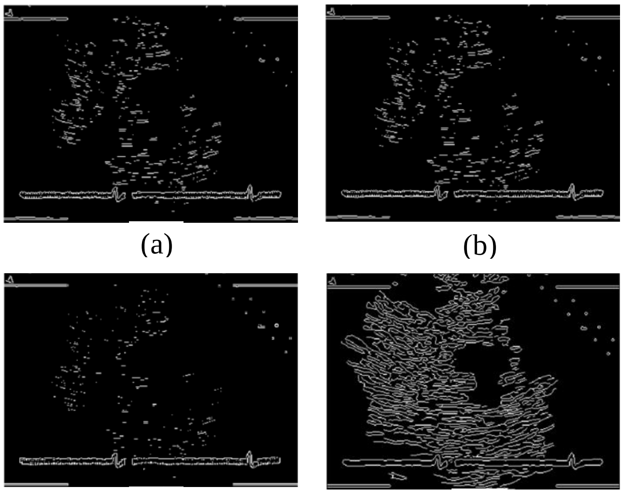
After the cavity center is selected, the cavity-center-based method identifies the endocardial boundary from the Canny image as shown in Fig. 5. This boundary looks good to represent the endocardium since almost the entire boundary is on the correct location of endocardium. However, there are several discontinuities and outlier coordinates which effect inaccurate boundary.




(a)

(b)

Figure 3. (a) Computed optical flow of two frames in Fig. 3; (b) Flow vectors inside myocardium and along boundary



(a) (b)

(c) (d)

Figure 4. Computed edge map using (a) Sobel, (b) Prewitt, (c) Roberts and (d) Canny

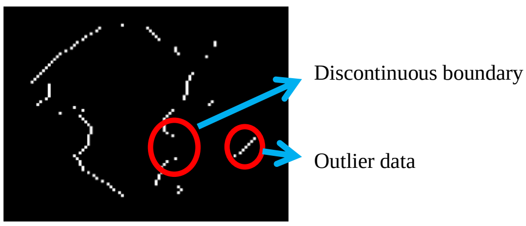
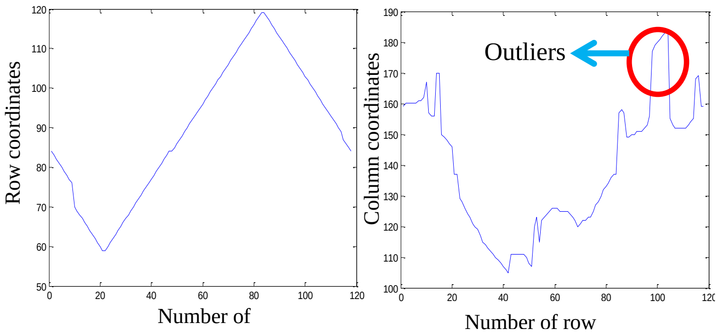



Figure 5. Endocardial boundary from Canny image

### *C. Identified Outliers*

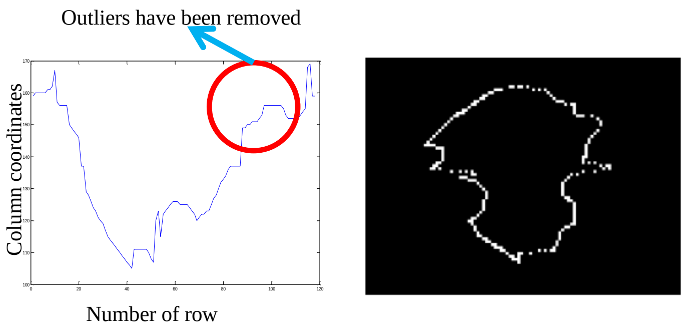
In order to ease the identification of outlier data, the initial boundary coordinates are represented by row and column profiles as shown Fig. 6(a) and (b), respectively. Fig. 6(a) shows that the row profile is well-ordered and looks smooth because the row is controlled variable in the cavity-center-based searching method. In contrast, the column profile as shown in Fig. 6(b) may represent the coordinates of endocardium. Thus, the identification of outliers should consider the column profile, instead of the row profile.




(a) (b)

Figure 6. (a) Row and (b) column profile of boundary coordinates in Fig. 6

Fig. 6(b) visually shows that there are outlier data on the coordinates. These outliers are then identified using interquartile range approach. Once detected, the outliers are then removed from the coordinate's data which is indicated by the column profile shown in Fig. 7(a). Finally, we come out with an enhanced endocardial boundary as shown in Fig. 7(b). Table 1 presents the endocardial boundary of different images data before and after enhancement process. By visual evaluation, the table gives evidences that the proposed method has ability to enhance the endocardial boundary in term of removing and reconnecting discontinuities. However, on several cases, the method fails to automatically reconnect the discontinuous points due to the too wide distance.




(a) (b)

Figure 7. (a) Column profile and (b) endocardial boundary after outliers removal

## 4. CONCLUSIONS

An enhancement method for endocardial boundary detection based on B-Spline and statitstical approach has been described. The method identifies discontinuous coordinates and outlier data using interquartile range and reconnects the points using B-Spline method. Although the evaluation is done visually, the results obviously confirm that the proposed method is able to enhance the endocardial boundary.

## ACKNOWLEDGMENTS

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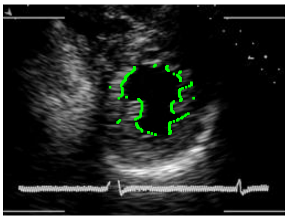
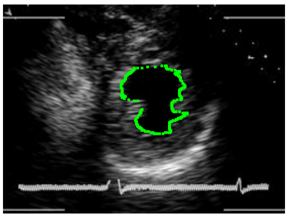
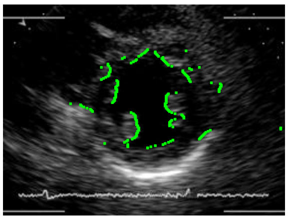
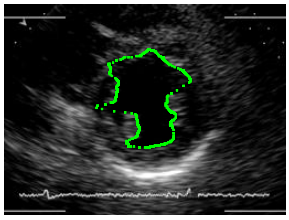
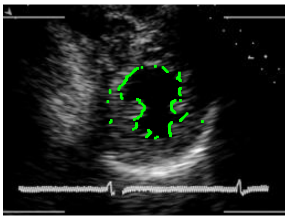
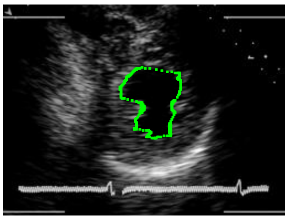
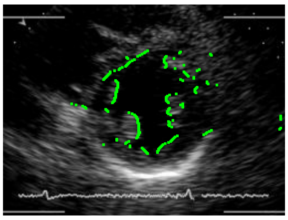
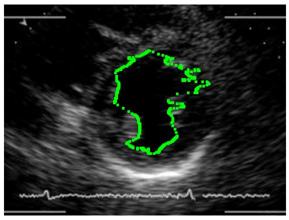
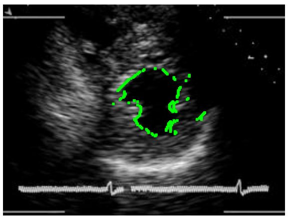
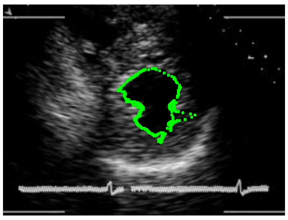
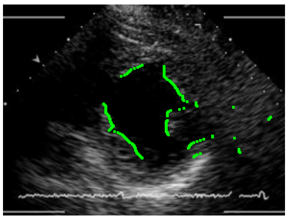
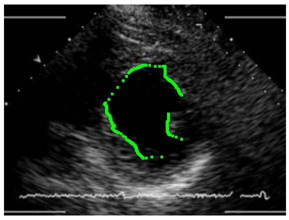
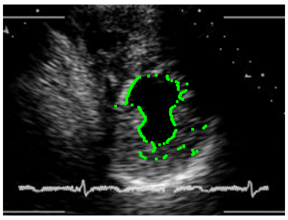
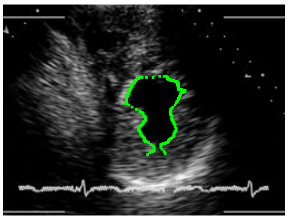
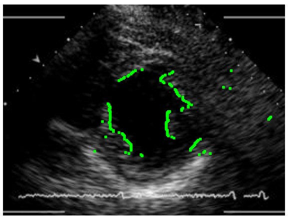
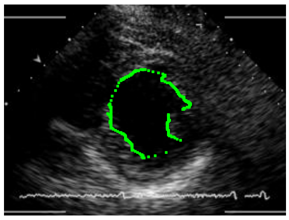
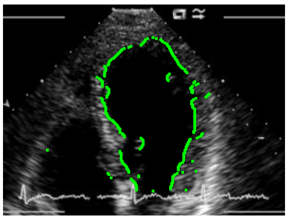
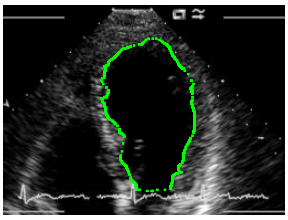
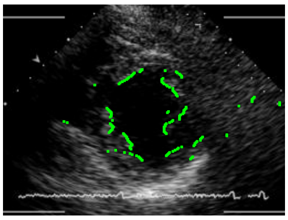
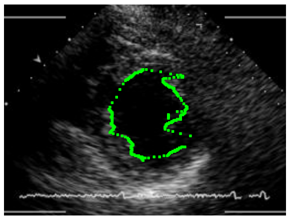
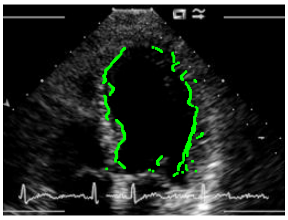
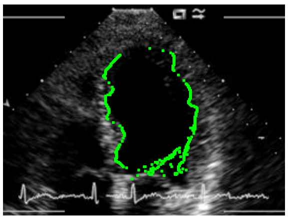
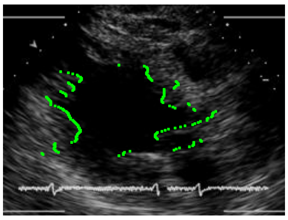
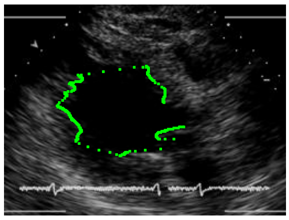
TABLE I. ENDOCARDIAL BOUNDARY BEFORE AND AFTER IMPLEMENTATION OF THE PROPOSED METHOD

| Before Enhancement | After Enhancement | Before Enhancement | After Enhancement |
|---|---|---|---|
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |