

Automatic Boundary Detection of Wall Motion in Two-dimensional Echocardiography Images

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Abstract: Problem statement: Medical image analysis is a particularly difficult problem because the inherent characteristics of these images, including low contrast, speckle noise, signal dropouts and complex anatomical structures. An accurate analysis of wall motion in Two-dimensional echocardiography images is “important clinical diagnosis parameter for many cardiovascular diseases”. A challenge most researchers faced is how to speed up the clinical decisions and reduce human error of estimating accurately the true wall movements boundaries if can be done automatically will be a useful tool for assessing these diseases qualitatively and quantitatively. **Approach:** The proposed method involves three stages: First, the pre-processing stage for image contrast enhancement to reduce speckle-noise and to highlight certain features of interest (i.e., myocardial tissue). In the second stage, we applied the segmentation process using thresholding technique by considering a mean value of pixels intensity as a threshold value to distinct image features (e.g., Background and object). After thresholding implementation, the two most common mathematical morphology operators ‘erosion’ and ‘dilation’ are applied to improve the efficiency of the wall boundary detection process. Finally, Robert’s operator is used as edge detector to identify the wall boundaries. **Results:** For accuracy measurement, the experimental results of the proposed method are compared to that obtained from medical QLab system qualitatively and quantitatively. **Conclusion:** The results showed that our proposed method is reliable and its performance accuracy percentages are 50% more acceptable and 42% better than QLab system results.

Key words: Echocardiography image, threshold value, edge detection, mathematical morphology operators, Robert’s operator, proposed method, QLab system, semi-automatic algorithm, boundary detection process, wall motion

INTRODUCTION

Two-dimensional echocardiography is a powerful tool for the diagnosis most of heart diseases that allow a qualitative understanding for heart morphology and function by direct visual observation of cardiac structure and movement. The basic goal in our work is

to detect true boundaries of the heart wall movements automatically through the complete cardiac cycle in order to assist the specialist in the assessment of common cardiac diseases. In particular, some clinical parameters can be evaluated qualitatively and quantitatively measurements of Left Ventricle (LV), Right Ventricle (RV), Left Atrium (LA), Right Atrium

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(RA), Valve size. Therefore, efficient and accurate boundaries detection of wall motion from echocardiography images has become a major research interest, which essentially requires several methods of image analysis.

In the literature, a few methods have been proposed to detect boundaries of wall motion automatically because the anatomical structure difficulties that still pose as a challenge to solve. Thus, most methods need to be manually drawn for initial contour or placed initial points. A fuzzy reasoning method based on local image characteristics that proposed to enhance the boundaries of echocardiogram (Sheila and Gopalakrishnan 2006). An automatic approach for segmentation and ventricular border detection is presented by combining k-means clustering and active contour model. This proposed method based on many calculations to determine desired LV cavity (Nandagopalan *et al.*, 2010). A semi-automatic algorithm of the LV segmentation is proposed to extract internal cavity border by combining classic image processing techniques with sequential radial search (Saulo *et al.*, 2008). The optical flow method is proposed to estimate velocities of the left ventricular wall segments and find relation between these segments motion to analyze the LV Wall Motion abnormality by 2D Echocardiography image (Hussein *et al.*, 2010). The Gray-Level Co-occurrence Matrix (GLCM) is a computerized technique which used for automated detection for bone fracture from X-ray (Chai *et al.*, 2011).

There are many techniques that are widely used in each stage of the image processing to obtain a reliable result for desired boundaries. High-boost filtering and Laplacian of the Gaussian (LoG) operator is applied to increase image contrast (Maria *et al.*, 2008). In the study of improvement of nuclear track density measurements are evaluated the well known edge detection methods; derivative operators (i.e. Sobel, Prewitt and Roberts), Laplacian of Gaussian (LoG) and Canny operator. The results showed that overall; Canny is the most precise and accurate than other techniques (Mostofizadeh *et al.*, 2008). The watershed transformation for image segmentation is used to extract the inner wall of LV as a region of interest (Salvador *et al.*, 2010). The vessel extraction is a very useful process for surgical and clinical study. The proposed method were improved to provide good results for coronary artery tree vessel extraction by setting the value of σ in the Gaussian function in the range $1 \leq \sigma \leq 2$ (Khalil *et al.*, 2010). Canny edge detector is applied to identify the myocardial boundary by finding zero-crossing (non-maximum suppression) along the edge of normal directions (Adhi *et al.*, 2010).

The aim of the proposed method is to develop boundary detection process for wall motion automatically by segmenting the image into distinct regions (i.e., blood and myocardial). The segmentation process is based on a threshold value which equals to average value of image pixels intensities. This step is a basic key of our work because it's applied automatically for all data unlike other methods as they need to test threshold value many times visually and then select the desired one which gives a good result.

MATERIALS AND METHODS

The proposed method works as a series of stages as follows:

- Convert the 2D echocardiography video into number of frames according to interval of time. Each frame is a 2D image of size 608×424
- Enhance image quality by increasing contrast and noise reduction
- Segmentation process involved two steps
- Segment image into background and object regions using thresholding technique
- Apply the mathematical morphology operators on segmented image to improve object's border
- Detect the wall boundaries using Robert's operator

Figure 1 presents those stages in terms of block diagram.

Pre-processing: Due to complex anatomical structure of echocardiography image, it causes two major problems; low contrast and speckle noise. Thus, two steps of pre-processing are needed for contrast enhancement and noise reduction to solve these problems without losing image features. In the first step, Min-Max linear contrast stretch method is applied for highlighting certain features of interest. In our work, this step is done automatically for once, depending on the intensities of pixels in original image but in QLab system, it has done according to the specialist decision if need to repeat it until obtained a good results by visual observation. Then in second step, we used Mean filter for noise reduction process, where mean filter is a linear technique which often applies as smoother to reduce noise in image. Smoothing process was implemented by replacing each pixel value in an image with the mean ('average') value of its neighbours, including itself. The size of neighbourhood usually is a 3×3 square kernel, but the larger kernels (e.g., 5×5) widely used in the medical images for more severe smoothing because they have the problems of speckle-noise and poor quality. Figure 2 shows the representative results that are obtained from pre-processing stage.

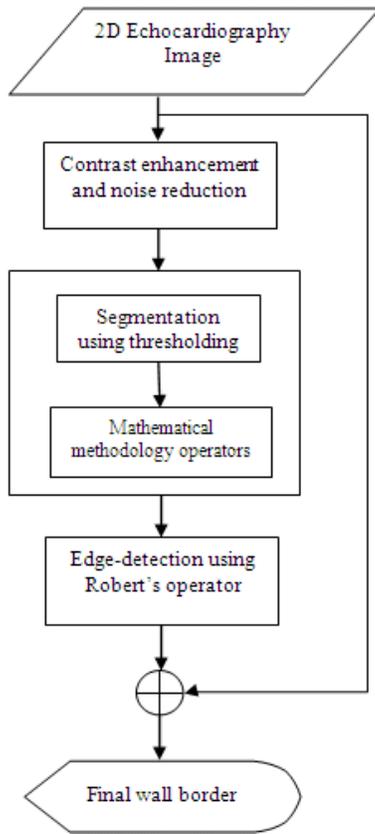


Fig. 1: Block diagram of the proposed method

Segmentation: The basic goal of segmentation process in echocardiography is to identify boundary points between blood and myocardial tissue. Thresholding is the simplest form of regional segmentation for converting a multilevel (grey scale) image into a binary image, to separate the foreground object(s) from the image background. In our proposed method, the implementation to this purpose is determined by a single parameter known as the intensity threshold which equals to average value of image pixels intensities. In a single pass, each pixel in greyscale image is compared with this threshold. If the intensity of pixel is higher than the threshold value, the pixel is set to intensity value equal '255'. If it is less than the threshold value, it is set to '0'. This step is a basic key of our proposed method because the threshold value computed automatically by the same way to all 2D echocardiography videos unlike the study of QLab system that needs to change threshold value manually from one video to other in case of unsatisfactory result.

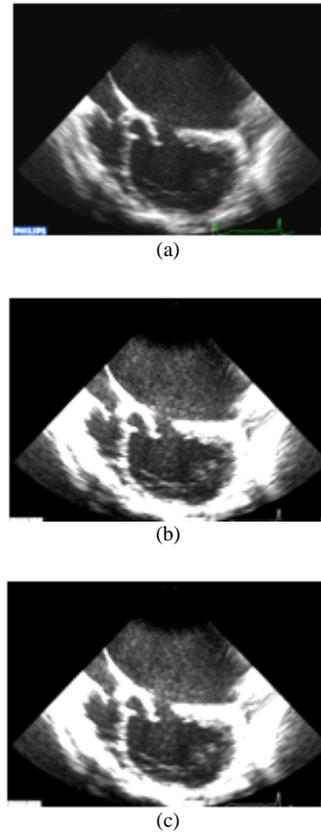


Fig. 2: Representative results from pre-processing (a) The original image; (b) Contrast-enhanced image; (c) Smoothed image after applying Mean filter

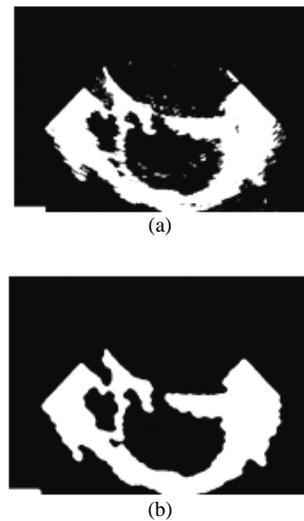


Fig. 3: The effect of thresholding and morphology operators (a) binary threshold image; (b) after opening operation

After thresholding implementation, the two most common mathematical morphology operators are used ‘erosion’ and ‘dilation’ as an important stage that is in need for more improvement to smooth the object’s border by removing small dark regions around the object and set all of the neighbours within 3 pixels of object’s to white. A process of erosion followed by dilation (i.e. Opening operation) was found to be successful in determining object’s region. Practically, in each erosion step, every object pixel that is touching a background pixel is changed into a background pixel. Likewise, in each dilation step, every background pixel that is touching an object pixel is changed into an object pixel. Figure 3 shows the effect of thresholding and morphology operators.

Edge detection: This is the final step in our proposed method that used to detect sharp transition calls ‘edges’ and to connect these edges to outline the desired boundaries. One of the gradient edge detectors that we use is Robert’s operator which is based on the form of most differential operators. It is a simple and quick way to compute for highlights regions of high spatial gradient that often corresponds to edges. In theory, the operator consists of a pair of 2x2 convolution masks as shown in Fig. 4. These masks are applied separately to the input image, to produce separate measurements of the gradient component in each orientation vertically Gx and horizontally Gy.

And to compute the orientation of that gradient, using:

$$|G| = \sqrt{G_x^2 + G_y^2} \tag{1}$$

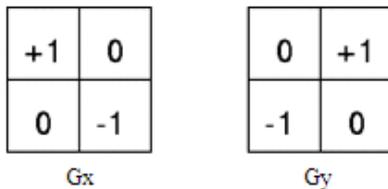


Fig. 4: Roberts’s convolution masks

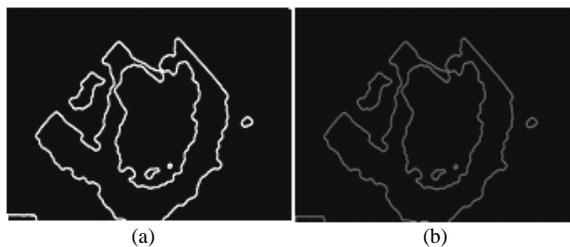


Fig. 5: The results of (a) sobel operator; (b) robert’s operator

These can then be combined together at each point in image to find the absolute magnitude of the gradient, using:

$$\theta = \arctan(G_y / G_x) - 3\pi / 4 \tag{2}$$

When compared the Robert’s operator results with other common edge detector for example the Sobel operator can see the edges are thinner and the computation takes less time as shown in Fig. 5.

RESULTS

All the echocardiography data used in this study have been taken from Philips medical machine that exists in one of the Malaysian hospitals (IJN). The data is divided into two sets: First set consists of 12 original videos of 2D Echocardiography belongs to 10 different patients, each one of these videos is converted into a number of frames according to interval of time. Each frame is a 2D image of size 608x424. Total numbers of frames for all videos are 409. The second set was used for comparison process which contains the same 12 videos but with complete borders that is one of the options in QLab system. The proposed method was coded in VB 0.6 under Microsoft Windows Professional, 2.9 GHz computer with 3.0 GB memory. Figure 6 shows the final results of wall boundary detection in (a) End-diastolic and (b) End-systolic frames after combining the original image and the resulted image by applying Robert’s operator.

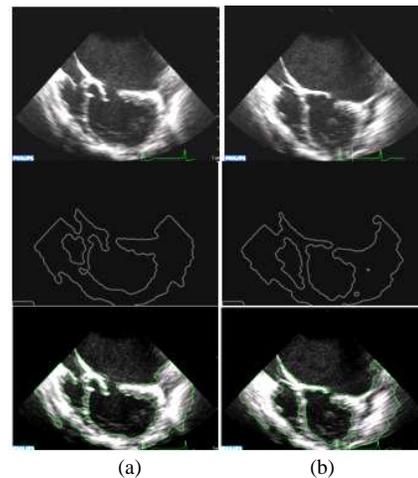


Fig. 6: The final results for the proposed method (a) end-diastolic and (b) end-systolic frames

DISCUSSION

For accuracy measurement, the experimental results of our Proposed Method (PM) have been compared with results that obtained from medical QLab System (QS) qualitatively and quantitatively. Qualitative comparisons process is done by visual subjective observation of the specialist (i.e. a cardiac technician) to make her/his decision according to the performance of results. This decision is represented as a score which is given as follows: 1: PM is worse than QS, 2: PM is similar to QS, 3: PM is more acceptable than QS and 4: PM is better than QS. Table 1 shows the qualitative validation for all data set. The results have shown the performance accuracy of our proposed method has 50% more acceptable and 42% better than QLab system results.

In order to evaluate the accuracy of the proposed method quantitatively, Pratt's Figure Of Merit (FOM) metric were used for the results comparison process (Karen and Eric, 2008). FOM returns a number between 0 and 1 based upon the quality of edge detection, with 1 being the ideal. These measured computations are based on distance comparison between the desired edges that are generated from complete border option in QLab system to the corresponding detected edge that is obtained from our proposed method. To do this comparison process, we need to separate the desired edge from QLab system data and then saved as new image after converted to binary. This process has been done by subtracting each pixel's intensity in the original image from corresponding pixel intensity in complete border image as shown in Fig. 7.

Table 1: The final results of qualitative validation

2D Echo videos	No. of Frames	Threshold value	1	2	3	4
V1	34	50				√
V2	22	47			√	
V3	32	36			√	
V4	53	47			√	
V5	21	60			√	
V6	52	50			√	
V7	12	50				√
V8	18	47			√	
V9	46	47				√
V10	44	50				√
V11	20	42				√
V12	56	50		√		

Table 2: The FOM average measurement

2D Echo videos	FOM average	2D Echo videos	FOM average
V1	0.39744	V7	0.36949
V2	0.41333	V8	0.62218
V3	0.43439	V9	0.52037
V4	0.52387	V10	0.48034
V5	0.60339	V11	0.61148
V6	0.55082	V12	0.53943

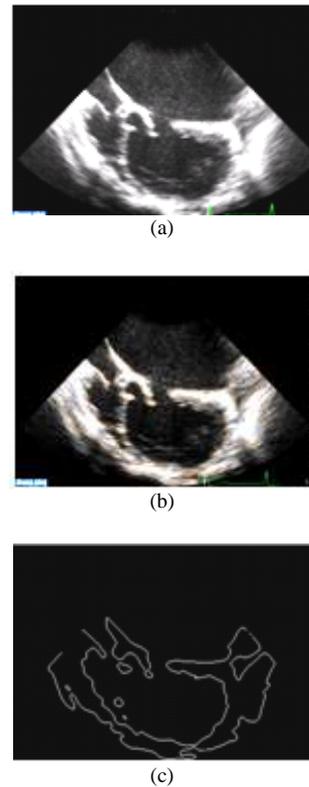


Fig. 7: The extracted boundaries of QLab system in (c) by subtracting (a) original image and (b) complete border image

Table 2 shows the average of FOM measurement. Figure 8 shows different examples of detected boundaries in end-diastolic frame for QLab system and the proposed method.

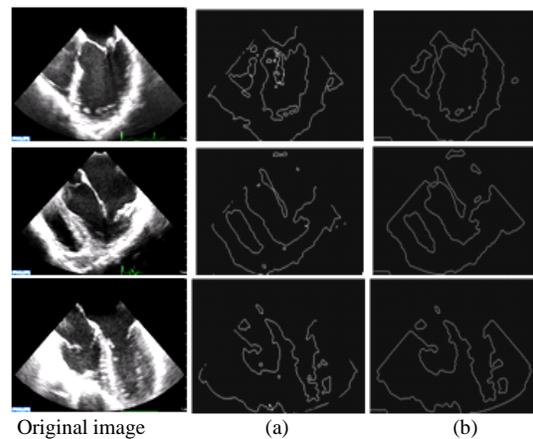


Fig. 8: Different examples of detected boundaries in End-diastolic frame for (a) QLab system (b) Proposed method

CONCLUSION

The aim of this study is to show that the detecting of the heart wall movement in 2D echocardiography images can be accomplished automatically through cardiac cycle using the most common techniques of image processing. Automatic segmentation by threshold value has achieved reliable results for extracting the region of interest (i.e., myocardial wall). In the context, the process of two erosion steps followed by two dilation steps was found successful and effective in getting good results for opening operation. The results showed that our proposed method is reliable and has 50% of the performance accuracy that more acceptable and 42% better than QLab system results. Therefore the proposed method could be a useful tool to the specialist for assessing many cardiovascular diseases.

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