Automatic Cardiac Segmentation Using Triangle and Optical Flow

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Abstract

Cardiac function assessment plays an important role in daily use of cardiology and ultrasound. Full automatic cardiac segmentation is a challenging study because cardiac ultrasound image has low contrast and irregular moves. In this research, full automatic cardiac segmentation for cardiac diseases is discussed. There are four techniques used in this research: Initial Center Boundary, Pre-processing, Triangle Segmentation and Optical Flow. The first step is to determine the initial center boundary. The second step is to use Pre-processing to eliminate noise. The third step is to use Triangle Segmentation to detect cardiac boundary and reconstruct the accurate border. The last step is to apply Optical Flow method to detect and track the border for every frame in a cardiac video. The performance segmentation for assessment errors cardiac cavity showed an average triangle 8.18%, snake 19.94% and watershed 15.97%. The experiments resulted in the fact that triangle method is able to find and improve the segmentation of cardiac cavity images accurately. The result shows that error between system and average of users is only less than 5.6%. This indicates that this method is effective for segmenting and tracking cardiac cavity in a cardiac video.

Keywords: cardiac cavity, center boundary, high boost filter, triangle equation, optical flow

1. Introduction

Cardiovascular disease will continue to be trends. The annual number of death will rise from 17.5 million in 2012 to 2.2 million by 2030. The dead rate of heart diseases had been recorded by WHO in Indonesia which reached 1.5 million people in 2014. Today, echocardiography is one of non-invasive solution mean in clinical cardiology. Echocardiography uses two or three-dimensional static image, and a moving image which provides information about size and shape of the heart chamber, pumping capacity and the location of tissue damage. Echocardiography also used for diagnosing and following-up treatment of the patients with suspected or known heart diseases [1]. The results on circumstances of echocardiography video only rely on the accuracy and physicians experience. This may cause the results of the analysis differ from each doctor and makes it difficult to determine the actual state [2]. The most common clinical echocardiography test to assess LV function by uses calculate ejection fraction [3]. The ejection fraction is an important measurement in determining how well your heart when pumping out blood, diagnosing and track heart failure [4].

Border detection cardiac images in short axis view are very useful in helping doctors to diagnose patient cardiac diseases. Various research and methods have been established to discovery cardiac cavity [5-17]. However, there is still room for novelty and development of methods and algorithms. To make segmentation and detection of echocardiographic images, a number of researchers have used short axis images [5−12], while others [13, 14] have used the long axis images. In [5, 8, 10], semi-automatic detection method was used, where-as in [7, 13] a fully automated detection method was developed. It is also interesting to note that in [9, 14, 15], the active contour models or snakes algorithm has been used to perform segmentation of cardiac cavity.

In [5], Klinger et al. applied mathematical morphology to carry out the segmentation of echocardiography images. Laine and Zong [6] provided border detection that traded on the shape modeling and border rebuilding from a set of images. Ohyama et al. [7] used ternary

threshold method for detection of the left ventricular endocardium. Maria et al. [5, 8] used up semi-automatic detection of the left ventricular border. Chalana and David [9] presented multiple active contour models for cardiac boundary detection. Lacerda et al. [10] used up a radial search for partition of cardiac images. Cheng et al. [13, 14] applied watershed segmentation for cardiac detection and located a center point in borderline. Santiago et al. [16, 17] presented segmentation of the LV in three-dimensional (3-D) echocardiographic. Sigit et al. applied segmentation of echocardiography images using triangle equation, snake, and watershed. The error value of triangle is lower than snake and watershed method [18,19,20,21,22]. Gualdron issued of vascular ultrasound image segmentation and proposed a novel ultrasonic vascular location and detection method [23]. Ting et al. [24] presented a new methodology directed to segmentation of left ventricular contours in angiographic images by using Generalized Hough Transform.

This study proposes automatic cardiac segmentation to trace boundary of endocardium in the left ventricular cavity at short axis view echocardiogram using triangle and optical flow. The tracking process is build at end-diastole to end-systole of one cardiac cycle. The technique consists of the initial center boundary, pre-processing, triangle segmentation, obtaining good feature, and optical flow. This technique can detect border of the cardiac cavity in the echocardiographic video very precisely.

2. Research Method

Improving methodology is coming in automatic cardiac segmentation. In a previous study [18], cardiac cavity segmentation is identified by a semi-automatic method in which we must determine two points to detect border of a cardiac cavity. The method which involves Initial Center Boundary, Pre-processing, Triangle Segmentation, Obtaining Good Feature, and Optical Flow is graphically described in a schematic diagram shown in Figure 1.
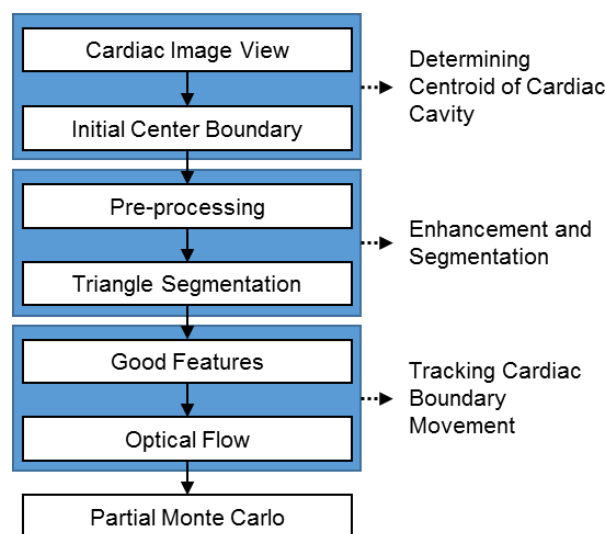

Figure 1. Flow Diagram of the Algorithm

2.1. Short Axis Echocardiographic View

Echocardiography can produce some types of echocardiographic video views such as short axis, long axis, A2C, and A4C. However, we used echocardiographic short axis video in this research. In medical echocardiography analysis, short axis view is the first video which obtained to determine to diagnose another cardiac view in an echocardiographic video. Echocardiogram has grayscale color space and has a lot of noise. The intensity of noise determines how clear the echocardiogram.

2.2. Initial Center Boundary

Automatic cardiac segmentation is done by defining initial of a boundary of a cardiac cavity in the echocardiogram. Echocardiogram contains considerable speckle noise, which is harmful for the boundary identification. The method to suppress noise is smoothing operation. After applying this process, some holes still exist, which connect region of a cardiac cavity to other false regions. The application of morphological operation using erosion can fill holes and connect boundary of cardiac cavity image. Then, the image is scanned pixel by pixel to find each connected component or boundary region of the cardiac cavity. The largest region is identified as the left ventricle cardiac cavity.

The x coordinate of centroid point in the left ventricle is calculated from an average of all x in the boundary region. The y coordinate of a center point in the left ventricle is calculated from an average of all y. The following equation is shown in Equation (1) and (2).

$$mx = \frac{1}{K}\sum_{k-1}^{K} X_k \tag{1}$$

$$my = \frac{1}{K}\sum_{k-1}^{K} Y_k \tag{2}$$

m(x,y) is a center of a boundary. The result from the center boundary calculation is shown in Figure 2.
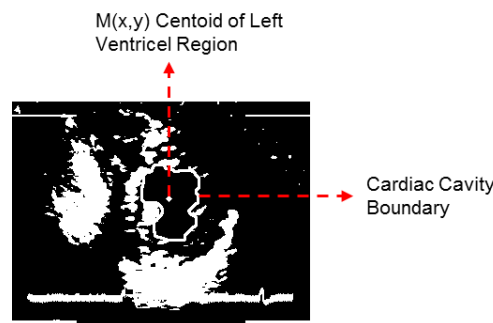

Figure 2. Result from center boundary calculation

2.3. Preprocessing

After centroid founded, the process is started from the first step that is pre-processing. The objective is to obtain boundary of cardiac in real size. The Pre-processing step is applying Median High Boost Filter to eliminate noise. Median High Boost is a new method that is a combination of median filtering and High Boost Filter. The median filter is low pass filter to eliminate speckle noise in the echocardiogram. High Boost filter is sharpness filter as shown in Figure 3.
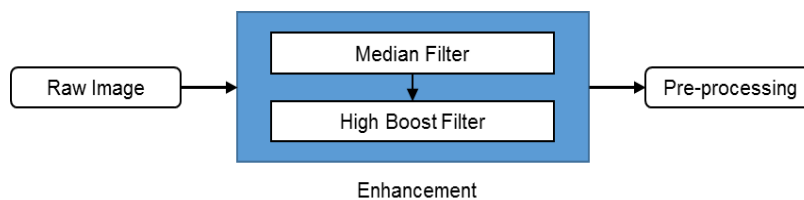

Figure 3. Pre-processing – Median High Boost Filter

After applying the median boost filter, the image will be applied the morphological operation with common procedures are opening and closing algorithm [5]. The main purpose of the opening and closing algorithm is to reduce speckle noise and thicken the cardiac cavity image. The opening algorithm involves eroding image A by B and dilation by B. mathematically this is achieved using the mathematical notation of the opening algorithm shown in Equation 3.

$$A \circ B = (A \ominus B) \oplus B \qquad (3)$$

Where $\ominus$ and $\oplus$ denote erosion and dilation, respectively.

$$A \cdot B = (A \oplus B) \ominus B \qquad (4)$$

The closing algorithm is implemented by dilating image A and eroding it by B. The mathematical notation of the closing algorithm is shown in Equation 4. Next, the negative Laplacian filter, which is a derivative filter, is realized to find areas of rapid change (edges) in the image. There are several ways to find approximate discrete convolution kernel that approximates the effect of laplacian. A possible kernel is shown in Equation 5.

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix} \qquad (5)$$

2.4. Triangle Equation
Triangle equation is the last step to segment left ventricle in the echocardiogram. Before it, region filter method is implemented with the aim to eliminate the small contours and obtain the main contour. The region filter scans all of the contours and calculates the area of each contour. Regions with an area that is smaller than the predetermined threshold are eliminated from the contour [10]. The threshold value was set to 25 pixels. And it was empirically determined.

The next step deals with the implementation of the collinear equation algorithm. The main purpose of such implementation is to optimize the number of contours by keeping and deleting some contours so that the resulted contour is closer to the actual boundary. This is achieved by finding the centroids of all existing contours using formula as shown in Equation 6.

$$centroid\ (C) = \left\{ \frac{\sum_{k=1}^{n} Xk}{n}, \frac{\sum_{k=1}^{n} Yk}{n} \right\} \qquad (6)$$

A collinear equation is carried out from center of the boundary to the centroid of each contour by finding the slope and intercept. The collinear equation used is as shown in Equation 7 – 9.

$$y = wx + b \qquad (7)$$

Where w and b are:

$$Slope(w) = \frac{n \sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2} \qquad (8)$$

$$intercept(b) = \bar{y} - w\bar{x} \qquad (9)$$

The next step is the practice of the triangle equation method. Figure 4 shows a representation of triangle equation, where A, B, and C are the corners. Label a is a distance between corner B and C, label b is a distance between corner A and C, label c is a distance between corner A and B. To calculate a distance between two disconnected points, triangle equation is proposed for solving it. The following formula as shown in Equation 10 and 11.
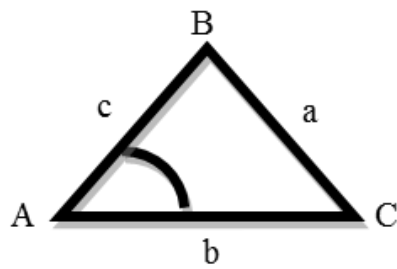
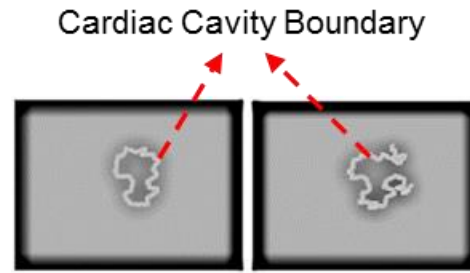Figure 4. Triangle Equation Illustration

Figure 5. The boundary of a cardiac cavity. (a) Close boundary. (b) Open boundary

$$a^2 = b^2 + c^2 - 2bc(\cos A) \tag{10}$$

$$A = \mathrm{acos}\left(\frac{b^2 + c^2 - a^2}{2bc}\right) \tag{11}$$

The previous process produces an image showing the cardiac cavity with open and closed boundaries. The boundary is closed when all points are connected, as shown in Figure 5(a). The boundary is open, if there are disconnected points or endpoints, as shown in Figure 5(b).

The boundary of the cardiac cavity can be obtained directly if the contour is closed, but if the boundary of the cardiac cavity is open, it can be obtained by using the triangle equation according to the following steps:
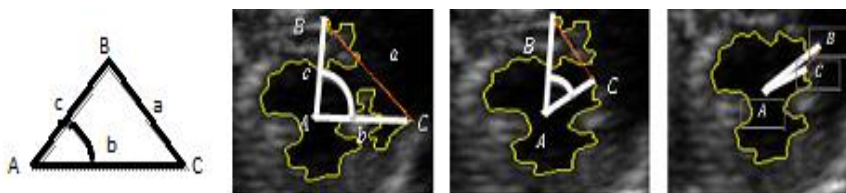

Figure 6. Triangle Equation on the cardiac cavity image

1. The first step is the centroid that had been founded as shown in Figure 2 as central point that is denoted as point A show in Figure 6(a).
2. The two endpoints of the boundary are located and are marked as points B and C in the same figure. The triangle BAC is formed from these three points with sides a, b and c.
3. The gap in the boundary is minimized by first fixing one of the end points, such as point B in Figure 6(b), and allowing point C to transverse inward along the boundary until the point at which the angle BAC is minimized is found. A similar action is then performed for point B to obtain the result shown in Figure 6(c).
4. The open boundary is then closed by connecting a line from point B to point C.

2.5. Good Features

Segmentation is used to separate object from the image background. The video is a collection of an image in sequential time. To segment video object, it must be extracted to be frame or image, firstly. A good feature of the object is a point of an image which has the unique feature than the others. Segmentation method is performed by automatic. In this step, the user will determine the starting point to detect position cardiac cavity at the start of diastole.

Generally, the position points of the cardiac cavity border at time t + 1 can be written as shown in Equation 12.

$$Q_{t+1} = f(Qt, Vt) \tag{12}$$

Qt (xt1, yt1, ..., xtn, ytn) is the position points of the cardiac cavity boundary at time t and v is the velocity vector of each point. The accuracy of tracking cardiac cavity boundary until the final conditions determined by the method of selecting a point at the initial conditions as shown in Figure 7.
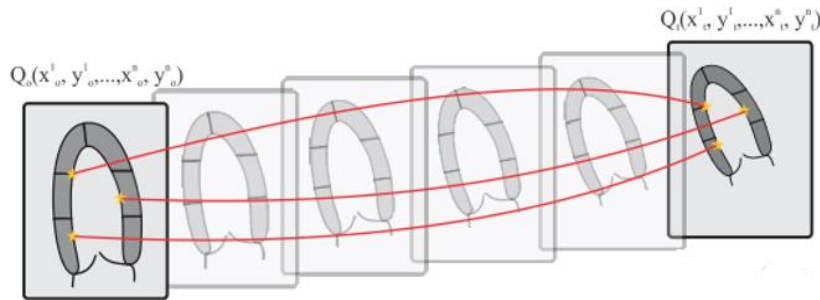

Figure 7. Tracking points of the Cardiac Cavity Boundary from Diastole to Systole

Where the position of the point (x, y) is selected automatically at the beginning of the first frame echocardiography video. The number of points which is selection more than 10 points. The number of points that have been selected will produce better segmentation and tracking cardiac cavity. Selection of the starting point of the view PSAX is planned according to the shape of the distribution LV segment (Left ventricle). Selection of the starting point should be at the heart cavity boundary which can be determined with certainty in order to produce the accuracy of the position until the end of the frame.

After that, all of the points will be smoothed using B-spline to get better cardiac cavity segmentation. The B-spline method is used to reconstruct the cavities of the heart. The selection starting point can not be determined because there is a lot of noise in the image echocardiography. By segmenting using B-spline will be able to resolve the border issue is lost or missing. In the B-spline using de Boor algorithm to find a new point on a b-spline curve.

By segmenting using B-spline has two advantages: (1) improve the tracking accuracy of the cardiac cavities and (2) handle the problem borders is interrupted or lost. In the B-spline, a point at x = tj known as knots or break-points and every spline function of order n on the set of knots can be expressed as a linear combination of B-spline as shown in Equation 13.

$$S_{n,t}(x) = \sum_i B_{i,n}(x) \tag{13}$$

Where i is the point of control and Bi,n (x) is a basis function on the degree n. To find the value Basis Function using the following equation 14 and 15.

$$B_{i,1}(x) := \begin{cases} 1 & if\ t_i \leq x < t_{i+1} \\ 0 & otherwise \end{cases} \tag{14}$$

$$B_{i,k}(x) := \frac{x - t_i}{t_{i+k-1} - t_i} B_{i,k}(x) + \frac{t_{i+k} - x}{t_{i+k} - t_{i+1}} B_{i+1,k-1}(x) \tag{15}$$

2.6. Optical Flow

Tracking Boundary of the cardiac cavity in the next frame is the last step. In this step, is used to cardiac cavity tracking for every frame in the echocardiography video. In this video, the border of the cardiac cavity is not clear and hard to track in the next frame because of the noise caused by the reflection process of the ultrasound waves. So, in this research to tracking cardiac cavity for every frame using optical flow method.

Point tracking using optical flow method is a form of very simple point tracking which tracked the object based on common features between before and after frames. This method using Lucas-Kanade algorithms because the method is easily applied to a subset of the points in the input image.

The disadvantage of using small local windows in Lucas-Kanade is that large motions can move points outside of the local window and thus become impossible for the algorithm to find. So, we also a development of the "pyramidal" LK algorithm, which tracks starting from the highest level of an image pyramid (lowest detail) and working down to lower levels (finer detail). Tracking over image pyramids allows large motions to be caught by local windows. On Figure 8, show direction point movement from the first frame to the next frame. This figure indicates that point of the boundary cardiac cavity moving to the left side.
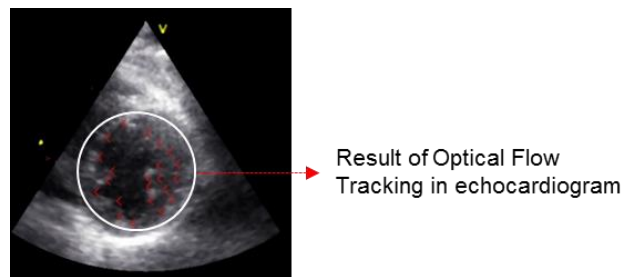

Figure 8. Shows point direction result optical flow method in the second frame

2.7. Partial Monte Carlo

Monte Carlo methods are stochastic techniques. The main purpose of this implementation is to calculation area of cardiac cavity images. Figure 9(a) shows Monte Carlo method for calculation cardiac cavity, where minX, minY, maxX, and maxY is the square of a boundary.

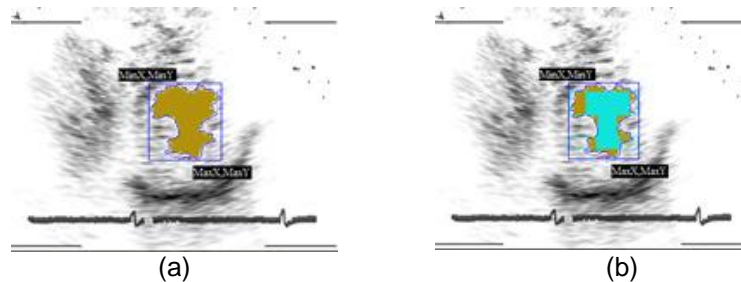(a)   (b)

Figure 9. Monte Carlo method for calculation cardiac cavity

If a total number of shaded part (nd) and total number random in the square (nt) are known, then the area can be calculated using equation 16.

$$Area = \frac{nd}{nt} * (maxX - minX) * maxY - minY)$$

(16)

Partial Monte Carlo is part of Monte Carlo algorithm. The purpose of this algorithm is to improve calculation faster than normal Monte Carlo. The idea is to divide the region boundary in several sections and search box in the area of the boundary. Figure 9(b) shows the partial Monte Carlo algorithm with the calculation area.

3. Results and Discussion

The proposed algorithm was tested using data set videos ultrasound from Hospital Dr. Soetomo Surabaya. The method uses Median High Boost (MHB) filter, Triangle Equation, and Partial Monte Carlo. The experiment results based on Pre-processing between mean, median, Gaussian, HB, and MHB as shown in Figure 10. MHB filter has the best image quality (PSNR = 57.2753) and has the ability to reduce noise (ENL = 0.5760).
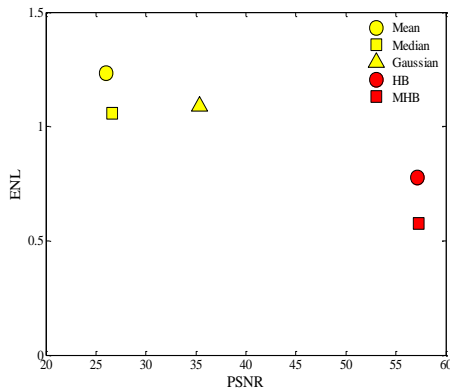

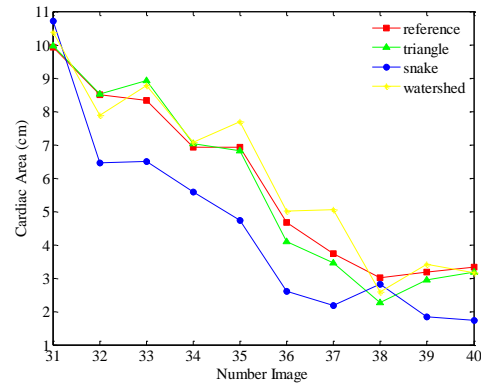Figure 10. The experiment result based on preprocessing

Figure 11. The experiment result based on segmentation

The experiment results based on segmentation between snake, watershed and triangle methods compared with the reference image shown in Figure 11. Triangular methods produce better segmentation than snake and watershed. Statistical analysis based on the results segmentation for 100 data as shown in Figure 12. Shown in box plots the error for triangle method has a smaller than the snake and watershed.
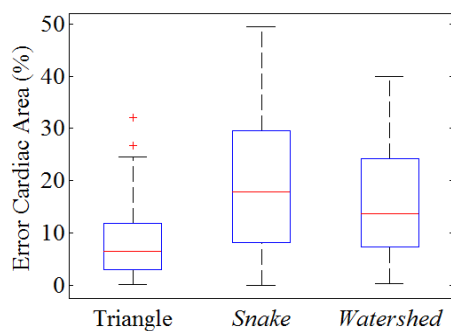

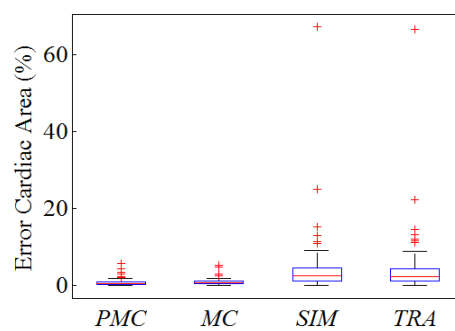Figure 12. Statistical analysis based on the results segmentation

Figure 13. The experiment result based on measurement cardiac area

In general, decisions and segmentation capabilities with comprehensive quantitative measurements showed that the border region segmentation using a triangle closer to the reference image or better result than using snake and watershed. The performance segmentation for assessment errors heart cavity obtained an average triangle 8.18%, snake 19.94% and watershed 15.97%. This achievement shows that the segmentation using triangle method has the smallest error value. These indicate where the triangle segmentation method is better than snake and watershed. The new method, named Partial Monte Carlo (PMC) has been created and compared to the measurement of the heart cavity area. The accuracy of the

method has been compared with the PMC comprehensive measurement method Monte Carlo (MC), Simpson (SIM) and trapezoidal (TRA) of the validity of the correct size.

The experiment results based on measure cardiac area between PMC, MC, SIM and TRA methods compared with the reference image shown in Figure 13. PMC methods produce better calculation cardiac area than MC, SIM, TRA, PMC, and MC. They have an average error of heart cavity that PMC is 0.64% and MC is 0.93%.

The experiment results based on a faster segmentation between snake, watershed and triangle methods as shown in Figure 14. Triangle method also has a faster segmentation than the others is 108 ms, while the snake is 1119 ms and watershed is 491 ms.
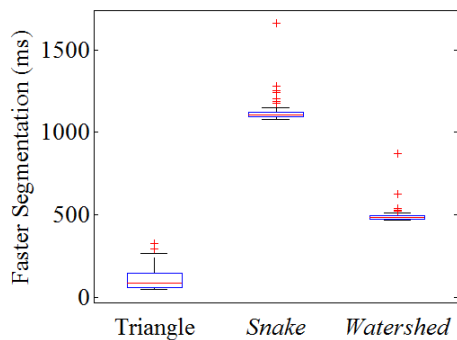

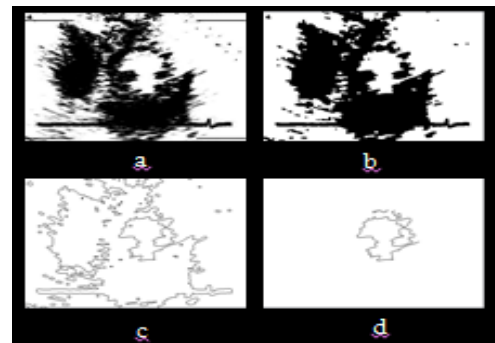Figure 14. The experiment result based on a faster segmentation

Figure 15. Result from the median high boost filter, morphological operation, laplacian and region filter

The result of the median high boost filter implementation is shown in Figure 15a followed by the results after morphological operation with thresholding in Figure 15b. It can be seen that high boost filter implementation yields an enhanced image of the cardiac cavity, which is further improved using morphological operations with thresholding. The result from the negative Laplacian filter implementation is shown in Figure 15c, while result after region filtering is shown in Figure 15d. This method used a collinear equation to keep and delete some contours; hence, the resulted contour is closer to the center boundary as shown in Figure 16. This method used triangle equation to reconstruct enclosed border. The images show that the method is finding the minimum small corner of a boundary in the contour as in Figure 17.
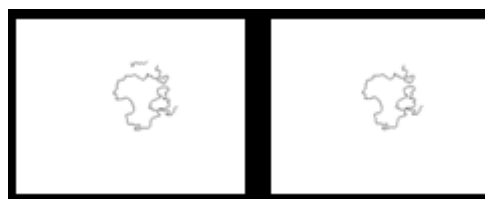

Figure 16. The method allows one to keep and delete contour

Testing initial points in this research using more than 20 points. That is will show a better reconstruct boundary cardiac cavity if we use initial points more than 20 points. This method also used optical flow method to track point of boundary cardiac cavity for every frame in echocardiography video as in Figure 18 and also show direction all of the points for every frame as in Figure 18. To see the effectiveness of tracking cardiac cavity using optical flow method in every frame, so we did testing the area of the cardiac cavity from this system and calculate an area of cardiac cavity manually from some user in every frame of echocardiography.
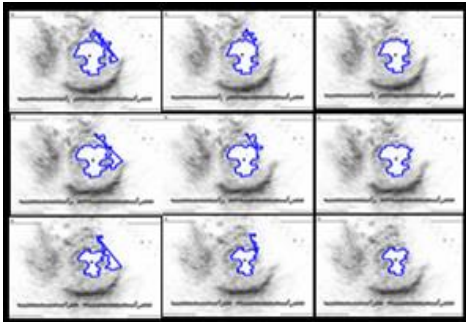
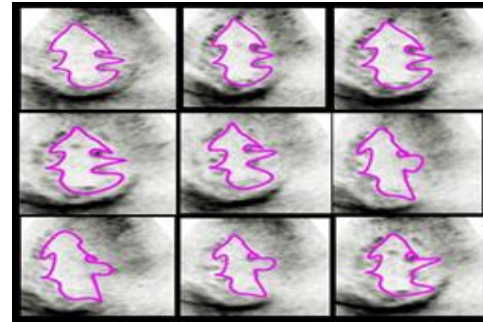Figure 17. The method is finding the minimum small corner of boundary

Figure 18. Result boundary of cardiac cavity optical flow method for every frame in video

From the Table 1, we compared testing frame of echocardiography video with 3 users. User-1(P1), User-2(P2), User-3(P3).   From the Table 2, we compared testing frame of echocardiography video between system and average of users. It can be seen that error between system and average of users is only 5.6 % and area of a cardiac cavity which got a result of 3 users almost same with the average standard deviation is 0.18. This indicates that this method is effective to tracking cardiac cavity in an echocardiographic video.

Tabel 1. Results area of cardiac cavity from users

Frame	Users			Average of users
	P1	P2	P3	
SAX_3.jpg	10,5416	10,4985	10,3374	10,45917
SAX_1.jpg	10,4995	11,426	10,5778	10,83443
SAX_8.jpg	7,74899	7,14019	6,87137	7,253517
SAX_6.jpg	8,56927	8,52481	7,7915	8,295193
SAX_4.jpg	9,8049	10,3318	9,05817	9,731623
SAX_5.jpg	9,61028	8,93047	9,208	9,249583
SAX_9.jpg	7,06112	6,9534	7,10514	7,039887
SAX_2.jpg	10,9534	10,0333	10,2216	10,40277

Tabel 2. Results area of cardiac cavity between system and users

Frame	Resut of tracking	Average of users	Error (%)	Standard deviation
SAX_3.jpg	10,8188	10,45917	3,324152	0,011585
SAX_1.jpg	11,1043	10,83443	2,43029	0,263996
SAX_8.jpg	8,4019	7,253517	13,66814	0,202186
SAX_6.jpg	9,09818	8,295193	8,825794	0,190774
SAX_4.jpg	10,1439	9,731623	4,064282	0,40956
SAX_5.jpg	9,51589	9,249583	2,798547	0,116832
SAX_9.jpg	7,91062	7,039887	11,00714	0,006094
SAX_7.jpg	8,60126	8,172893	4,980278	0,08226
SAX_2.jpg	11,1109	10,40277	6,373321	0,236262

4. Conclusion

The proposed method presents a solution for segmentation of echocardiography image for heart disease. This research has produced Median High Boost Filter that is able to reduce noise and maintain image information. The segmentation using triangle equation method has the smallest error value. The performance segmentation for assessment errors cardiac cavity obtained an average triangle 8.18%, snake 19.94% and watershed 15.97%. The experiments represented that the extended method is able to detect and improve the segmentation of cardiac cavity images with precise and faster.

Acknowledgment

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