Left Ventricle Segmentation from Heart ECHO Images Using Image Processing Techniques

Ye Naing Oo, Aung Soe Khaing.

Abstract— **Cardiovascular diseases are the major causes of mortality in the world. The most important and widely used tool for accessing the heart state is echocardiography(also abbreviated as ECHO).ECHO images are used e.g. for location of any damage of heart tissues, in calculation of cardiac tissue displacement at any arbitrary point and to derive useful heart parameters like size, shape, cardiac output and ejection fraction. In this paper, an algorithm for Left Ventricle (LV) segmentation of heart in ECHO images is presented. The left ventricle delivers the requirement of blood to all the parts of body and so it is important to consider the condition of left ventricle. It is based on the level set method. The main idea of the level set method is to get the ROI (Region of Interest), using velocity term F, speed term D, gradient value of ϕ, first order derivative, mean curvature K and second order derivative. Then, the segmentation of the LV is obtained.**

Index Terms— **echocardiography, left ventricle segmentation of heart, level set method, ROI (region of interest)**

I. INTRODUCTION

Every year cardiovascular system diseases are the reason of over 7 million mature demises in the world. One of the main cardiovascular risk factors is hypertension, leading among others to left ventricle (LV) rebuilding.

Estimation of left ventricle shape in ultrasonic echocardiographic images (ECHO) is recognized as the one of the main non-invasive methods of accessing the risk of heart and cardiovascular diseases.

Echocardiography (echo or echocardiogram) is a type of ultrasound test that uses high-pitched sound waves to produce an image of the heart. The sound waves are sent through a device called a transducer and are reflected off the various structures of the heart. These echoes are converted into pictures of the heart that can be seen on a video monitor. Ultrasound gel is applied to the transducer to allow transmission of the sound waves from the transducer to the skin

The transducer transforms the echo (mechanical energy) into an electrical signal which is processed and displayed as an image on the screen.

The conversion of sound to electrical energy is called the piezoelectric effect.

Due to the complexity of heart internal structures, the presence of strong disturbances in ultrasonic images (speckles, specular reflections, echoes, shadows and Gaussian noise) and low contrast in case of fine structures, LV shape segmentation is a difficult and time-consuming task. Evaluation of LV rebuilding progression in time is an additional challenge due to very high value of estimation error as a result of significant distinctions in LV outline produced by different physicians [5].

Image segmentation should consist of (1) filtering to reduce disturbances and enhancement of edge, (2) calculation of region of interest (ROI) and segmentation procedure [6].

In this paper, an approach to ECHO image segmentation based on Level Set method is presented.

The following figures show the ECHO machine and example of interesting ECHO structures image.

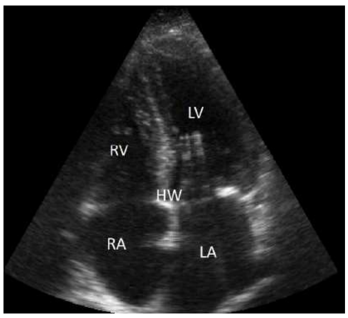

Fig-1: (Above) ECHO machine from Mandalay General Hospital, Myanmar. (Below) Example of ECHO image, four

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chamber view, RV – right ventricle, LV - left ventricle, RA – right atrium, LA - left atrium, HW – Heart walls

II. Image Segmentation techniques and their advantages and disadvantages

A. Image Segmentation Techniques

Images are considered as one of the most important medium of conveying information in the field of computer vision, by understanding the information extracted from images that can be used for the navigation of robots, extracting malign tissues from body scans, detection of cancerous cells and identification of runway from the satellite images, etc.[9]. There is a method help us to understand images and extract information or objects. This is the image segmentation method. It is the first step in image analysis. If there is noise, they are removed by the image de-noising filter for the purpose of diagnosis of disease without loss of information.

Image segmentation refers to the process of partitioning a digital image into multiple segments i.e. set of pixels, pixels in a region are similar according to some homogeneity criteria such as colour, intensity or texture, so as to locate and identify objects and boundaries in an image [9]. Practical application of image segmentation range from filtering of noisy images, medical applications (locate tumours and other pathologies, measure issue. volume, computer guided surgery, diagnosis and treatment planning, study of anatomical structures of echocardiographic images), locate objects in satellite images (road, forests, etc.), face recognition, finger print recognition, etc. The choice of a segmentation technique over another and the level of segmentation are decided by the particular type of image and characteristic of the problem being considered. Not all segmentation techniques are considered good for different images [17]. So, algorithm development for one class of image may not always be applied to other class of images. Therefore, the selection of an appropriate technique for a specific type of image is a difficult problem. Only the left ventricle from the image should be segmented.

B. Advantages and Disadvantages

The following are the various image segmentation methods to perform the solution.

(1).Edge-based

This method attempts to resolve image segmentation by detecting the edges or pixels between regions that have rapid transition in intensity are extracted and linked to form closed object boundaries [9]-[15]. This method works well for images having good contrast between regions. But, it doesn't work well with images in which the edges are ill-defined or too many edges .It is also less immune to noise than other methods.

This method detects all the edges of heart.

(2).Region-based

This method is relatively simple and more immune to noise [14]. Region based method partitions an image into region that are similar according to a set of predefined criteria [9]. Obviously, it doesn't work well for image without obvious peaks and also doesn't consider the spatial detail & so cannot guarantee that segmented regions are contiguous.

This method splits all the region and also contain the information of the entire heart.

(3).Thresholding

This method assigns a suitable threshold value to decide the region below threshold value as 0 and equal or above threshold value as 1. This requires the histogram of an image which has a number of peaks, each correspond to a region. This method doesn't need prior information of image & has less computational complexity. Unfortunately, this one doesn't work well for image without obvious peaks and also doesn't consider the spatial detail & so cannot guarantee that segmented regions are contiguous [12].

This method also contains the entire region of heart.

(4).Clustering

Clustering is an unsupervised learning task, where one needs to identify a finite set of categories known as cluster to classify pixels [17]. Clustering uses no training stages rather train themselves using available data. Clustering is mainly used when classes are known in advance. The advantages are Simplicity & low computational complexity. Its drawback is that the number of clusters must be determined & it doesn't give the same result each time the method is executed. This will cause the mistake.

(5).Active contour or snake

Active contour or snake is the computer generated curves that move within the image to find objects boundaries under the influence of internal and external forces. First, a snake is placed near the contour of ROI. During an iterative process due to various internal and external forces within images,, the snake is attracted towards the target. These forces control the shape and location of the snake within the image.

An energy function is constructed which consist of internal and external forces to measure the appropriateness of the Contour of ROI, Minimize the energy function (integral), which represents active contour's total energy, The internal forces are responsible for smoothness while the external forces guide the contours towards the contour of ROI. the energy function often converge to minimum local energy, so snake should be placed usually near the boundary of ROI [16], original snake algorithm is particularly sensitive to noise. More sensitive to the choice of its parameters and adaptively adjusts the parameters in an extremely complex process. This technique contains key concepts of region-based & edge-based. It can refine the object boundary. The advantages are computational complexity is high; include complex procedures, multiple parameter selection, and sensitive to initial contour location. The contour cannot handle topological changes, sharp edges & cusps [15]-[16]. This one can be a proper solution because it can segment the required region.

(6).Level Set Method

This method is developed by Osher and Sethian and is very influential and useful. The idea is to represent the curves or surfaces as the zero level set of a higher dimensional surface [4]. It has several advantages; highly versatile, accurate, robust & efficient technique than others for a wide class of complex problems & no need to parameterize the object. Stability & irrelevancy with topological changes help to solve the problem of corner point producing, curve breaking & combination. According these, this method is chosen to be the required solution than active contour or snake. Its disadvantages are computational complexity is high. It requires considerable thought in order to construct appropriate velocities for advancing the level set function.

(7).Watershed Method

The marker based watershed segmentation can segment unique boundaries from an image or stack of images by displaying several colours. The region contour adheres well to real object boundaries. Results are connected region with enclosed boundaries of single pixel wide. However, its weaknesses are over segmentation, sensitivity to noise, poor performance in low-contrast boundaries & poor detection of thin structures [2].

This method can display all the segment of region of LV, RV, LA and RA.

III. An Automatic Determination of Image Area

A. Initial Mask and Parameters

First of all, all the images are needed to convert from RGB to gray scale image. Then, the user needs to set the initial mask according to the required image area and to specify parameters for threshold values T, range E and curvature weighting factor α. Then the program will run and draw a closed polygon that will form the initial mask [7]. MATLAB version R2010a is used to perform the segmentation procedure.

B. Signed Euclidean Distance Transform

Signed Euclidean Distance Transform (SEDT) assigns a value for every pixel within a binary image containing one or more objects. This value represents the minimum distance from that pixel to the closest pixel on the boundary of the object. The mathematical formula of a Euclidean distance between points (a,b) and (c,d) is

$$\sqrt{(c-a)^2+(d-b)^2}$$

A signed distance transform assigns the sign of the distance value as positive for those pixels outside the object, and negative for those inside it. The distance values depend on the chosen metric for distance: some common distance metrices are Euclidean distance, Chessboard distance and City Block distance.

Signed distance transform are required to initialize ϕ and also to reinitialize it every certain number of iterations. The choice of how often to reinitialize is an important Curvature terms and one: if the number of iterations between reinitialization is too low the level set will oscillate, if it is too high the risky of instabilities is elevated.

IV. Implementation

Feature input image I, initial mask m, Threshold value T, Range ε, Iterations N and Reinitialization of every RITS are assigned first. Then the level set ϕ_0 is initialized to Signed Euclidean Distance Transform (SEDT) from the mask m. The evolution of the contour is by means of a level set equation. This is done by computing the derivatives iteratively and updating ϕ at each time interval.

The segmentation method is based on the following block diagram.

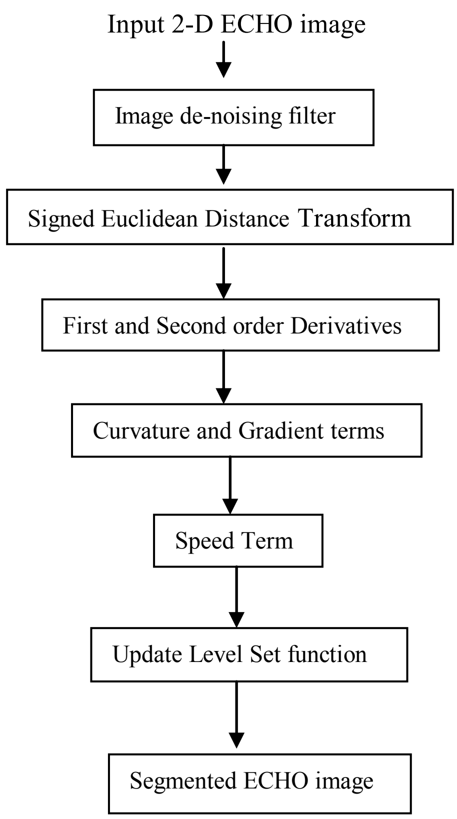

Fig-2: Block diagram of the Level Set method

The general form of the level set equation is defined as

$$\phi(t+\Delta t)=\phi(t)+\Delta t.\mathrm{F}.|\nabla\phi| \quad (1)$$

F =velocity term that shows the level set evolution which base on pixel intensity & curvature

$\nabla\phi$ =gradient of ϕ

ϕ(t)=current value of ϕ at time t

ϕ(t+Δt)=updated level set function

The velocity term is

$$F= -\alpha D(I)+(1-\alpha).K \quad (2)$$

α=free parameter to control how smooth the contour should be

D(I)= speed function by Lefohn, Whitaker & Cates

K= mean curvature term keeps the level set function smooth

The speed term is

$$D(I)=E-|1-T| \quad (3)$$

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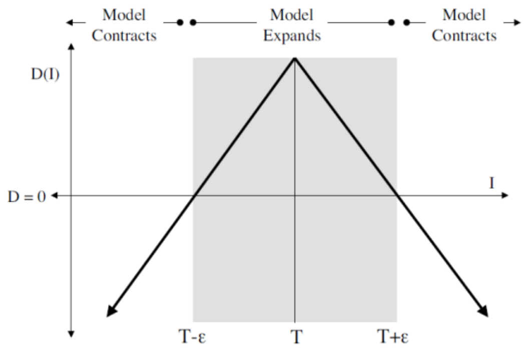

Fig 3(a): The speed term form

ε=intensity deviation range

T=central intensity valueof the region to be segmented

The level set equation needs to be discretized for sequential computation. This is done using the upwind scheme [4].

$$\phi(t+\Delta t) = \phi(t) + \Delta t.\mathrm{F}.|\nabla\phi|$$

$$\frac{\phi(\mathrm{t}+\Delta\mathrm{t})-\phi(\mathrm{t})}{\Delta\mathrm{t}} - \mathrm{F}|\nabla\phi| = 0$$

(4.1) $$\frac{\phi(\mathrm{t}+\Delta\mathrm{t})-\phi(\mathrm{t})}{\Delta\mathrm{t}} - \left(\mathrm{U(t)}\phi_x(\mathrm{t}) + \mathrm{V(t)}\phi_y(\mathrm{t})\right) = 0$$

where U(t) and V(t) are x, y components of F. $\phi_x(t)$ & $\phi_y(t)$ are the spatial derivative of $\nabla\phi$.

For simplicity, consider the one dimensional form at a specific grid point x,

(4.2) $$\frac{\phi(\mathrm{t}+\Delta\mathrm{t})-\phi(\mathrm{t})}{\Delta\mathrm{t}} - \left(\mathrm{U(t)}\phi_x(\mathrm{t})\right) = 0$$

If U(t)>0, the values of ϕ will move from left to right, then backward difference method D_x^- should be used. If U(t)<0, the values of ϕ will move from right to left, then forward difference method D_x^+ should be used to approximate $\phi_x(t)$. This process of choosing which approximation for the spatial derivative of ϕ to use based on the sign of U(t),is known as upwind scheme.

Extending to two dimensions result the derivatives below required for the level set equation update.

$$\mathrm{D}_x^+ = \phi_{i+1,j} - \phi_{i,j}, \mathrm{D}_x^- = \phi_{i,j} - \phi_{i-1,j}$$

$$\mathrm{D}_y^+ = \phi_{i,j+1} - \phi_{i,j}, \mathrm{D}_y^- = \phi_{i,j} - \phi_{i,j-1}$$

Δϕ is approximated using the upwind scheme,

(5.1) $$\nabla\phi = \begin{cases} \|\nabla\phi_{max}\|_2 \text{ if } \mathrm{F}_{i,j} > 0 \\ \|\nabla\phi_{min}\|_2 \text{ if } \mathrm{F}_{i,j} < 0 \end{cases}$$

(5.2) $$\nabla\phi_{max} = \begin{pmatrix} \sqrt{\max(\mathrm{D}_x^+,0)^2 + \max(-\mathrm{D}_x^-,0)^2} \\ \sqrt{\max(\mathrm{D}_y^+,0)^2 + \max(-\mathrm{D}_y^-,0)^2} \end{pmatrix}$$

(5.3) $$\nabla\phi_{min} = \begin{pmatrix} \sqrt{\min(\mathrm{D}_x^+,0)^2 + \min(-\mathrm{D}_x^-,0)^2} \\ \sqrt{\min(\mathrm{D}_y^+,0)^2 + \min(-\mathrm{D}_y^-,0)^2} \end{pmatrix}$$

Mean Curvature is

(6.1) $$K = \frac{1}{2}\nabla\frac{\nabla\phi}{\|\nabla\phi\|} = \frac{1}{2}\left[\left(n_x^+ - n_x^-\right) + \left(n_y^+ - n_y^-\right)\right]$$

The two normals n^+ and n^- are used to get the divergence.

(6.2) $$n^+ = \begin{pmatrix} n_x^+ \\ n_y^+ \end{pmatrix} = \begin{pmatrix} D_x^+ \Big/ \sqrt{(D_x^+)^2 + (\frac{D_y^{+x} + D_y}{2})^2} \\ D_y^+ \Big/ \sqrt{(D_y^+)^2 + (\frac{D_x^{+y} + D_x}{2})^2} \end{pmatrix}$$

(6.3) $$n^- = \begin{pmatrix} n_x^- \\ n_y^- \end{pmatrix} = \begin{pmatrix} D_x^- \Big/ \sqrt{(D_x^-)^2 + (\frac{D_y^{-x} + D_y}{2})^2} \\ D_y^- \Big/ \sqrt{(D_y^-)^2 + (\frac{D_x^{-y} + D_x}{2})^2} \end{pmatrix}$$

Curvature is computed based on the values of the current level set using the second order derivatives below [3].

$$\mathrm{D_x} = (\phi_{i+1,j} - \phi_{i-1,j})/2$$

$$\mathrm{D_y} = (\phi_{i,j+1} - \phi_{i,j-1})/2$$

$$\mathrm{D}_x^{+y} = (\phi_{i+1,j} - \phi_{i,j})/2$$

$$\mathrm{D}_x^{-y} = (\phi_{i,j} - \phi_{i-1,j})/2$$

$$\mathrm{D}_y^{+x} = (\phi_{i,j+1} - \phi_{i,j})/2$$

$$\mathrm{D}_y^{-x} = (\phi_{i,j} - \phi_{i,j-1})/2$$

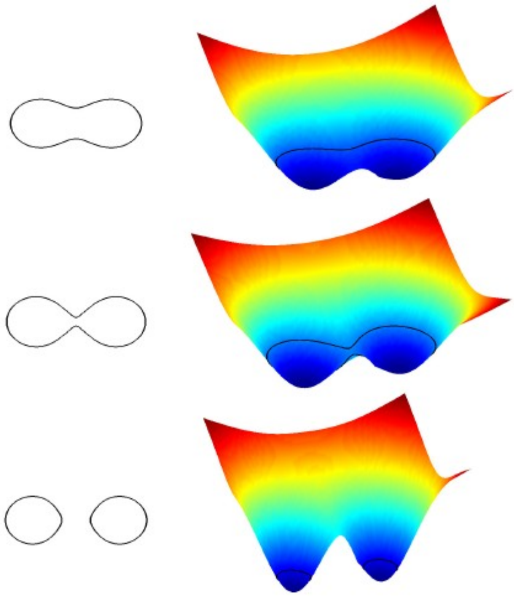

Fig – 3(b): The relationship between the level set function (left) and contour (right) can be seen.

V. Segmentation Results

The segmentation results are displayed as follows: images for input image 1, initial mask assigned by the user, iteration 20, iteration 100, iteration 500 and iteration 1000 are shown. After that, images for input image 2 and iteration 1000 are also shown.

Fig-4(a): Input image 1

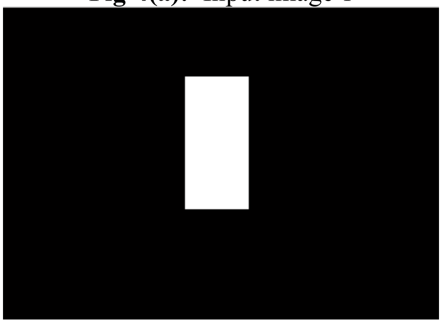

Fig-4(b): Initial mask

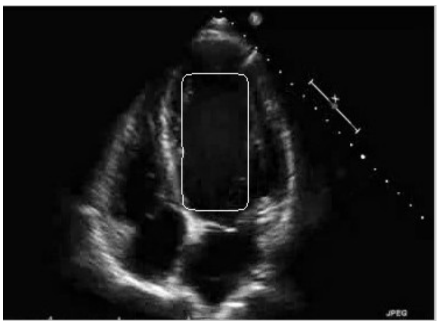

Fig-4(c): Iteration 20

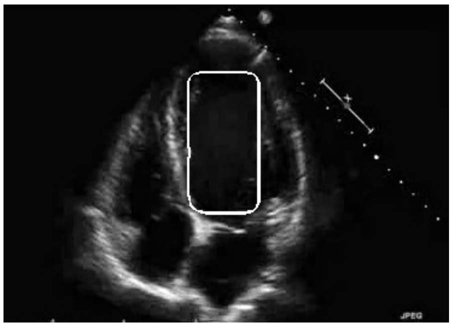

Fig-4(d): Iteration 100

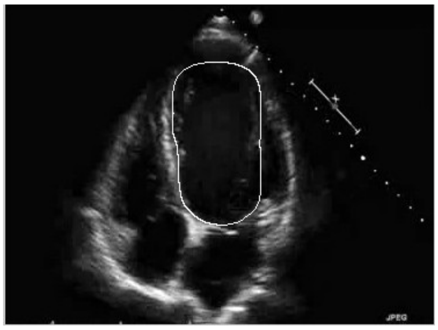

Fig-4(e): Iteration 500

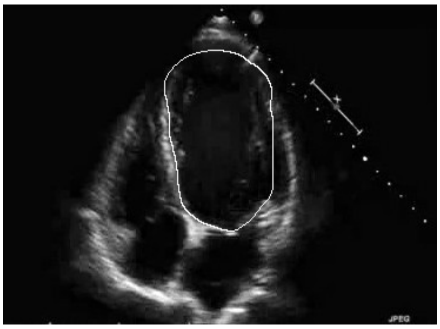

Fig-4(f): Iteration 1000

Fig-5(a): Input image 2

Fig-5(b): Iteration 1000

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The described algorithm has been tested on a few real echocardiography images sequences.

Assessment of the heart shape estimation quality should consist of two parts. The first one is the shape estimation in ECHO data, and second: the shape mapping accuracy of medical imaging devices (e.g., Computed Tomography [4]). The author focuses on the first part.

Six images from three different ECHO machines are obtained and segmented by the Level Set method. In the following figures, white contours mark the shapes of the left ventricle estimated by the described method. It can be observed that the algorithm is working stably all the time and the contour evolution is kept inside a diagnostically relevant area even though their dimensions are different according to the different machines. The results are shown in the following figures.

When the shape of the left ventricle is estimated, one can easily calculate changes of the area of the left ventricle during heart systole and diastole. During systole, the heart contracts and pumps blood to the arteries where as in diastole, the heart relaxes and the chambers are filled with blood.

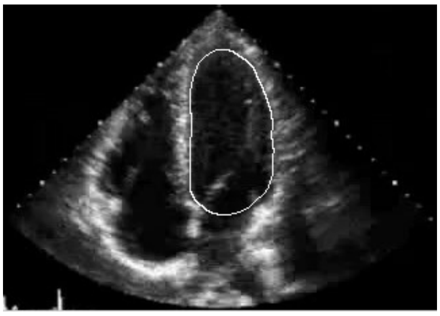

Fig-6:(a)

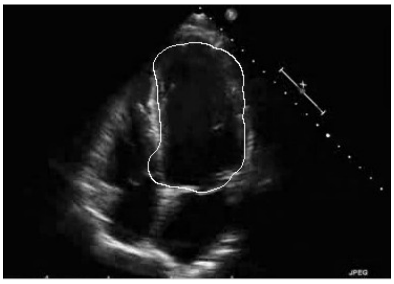

Fig-6(b)

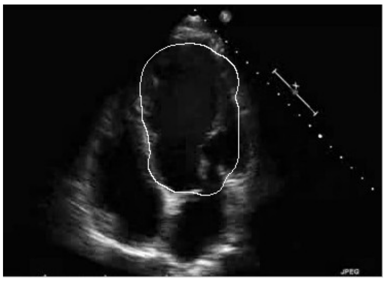

Fig-6(c)

Fig-6(d)

Fig-6(e)

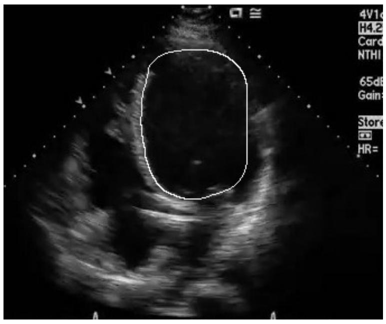

Fig-6(f)

Fig-6(a), (b), (c), (d), (e), (f) : Six Segmented ECHO images

VI. CONCLUSION

The segmentation is a very important step of digital image processing technique to extract information from the images. The results are useful for describing the information and making decision for various purposes. A method for automatic segmentation of heart structures in ECHO images is presented in this paper. In all the experiments, parameters of the algorithm are set in the following way: ε=35, T=45, α=0.03. If these values are so large, the contour will dilate and too small, the contour will erode. The maximum number of iteration is 1000, and the iteration is reinitialized every 50 iteration. The program running time for one image is about 20 minutes as the program is in sequential computation. So, the program is needed to implement in parallel computation in order to get fast running time. The described algorithm was implemented in MATLAB language on Intel Core i3 1.80 GHz, 4 GB RAM.

The described algorithm involves the SEDT and level set method: velocity term, speed term, mean curvature, gradient of ϕ, first order derivatives, second order derivatives and normal. The contour is displayed every 20 iteration. Then the iteration is reinitialized every 50 iteration. The number of

iteration in this algorithm is 1000. All the images are in JPG format and their dimensions are not the same. If the iteration is not enough, the contour cannot handle the desired region. If the iteration is over, the over segmentation will occur and it will lead to make wrong decision and decrease accuracy.
In future work, the accuracy and the left ventricle area will be calculated to determine that the heart is normal or abnormal (e.g., dilated cardiomyopathy).This will be valuable information for the diagnosis of heart disease.

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Biographies

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