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Automatic segmentation of echocardiographic Left Ventricular images by windows adaptive thresholds

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Abstract: The extraction of cardiac borders, particularly, the ones related to the left ventricle (LV), is an important goal to estimate some indices of great clinical value, such as, the thickness of the wall, ejection fraction, and regional wall motion, as the most used to assess the LV function. The accuracy of those indices depends on the correct LV boundary extraction. In this work, two LV segmentation algorithms are implemented: differencing method applied to the intensity profiles and the windows adaptive thresholds by Otsu algorithm. Results provided by the two techniques will be analysed considering factors like accuracy in the boundary extraction, effect of some artifacts like papillary muscles, intra-cavity structures, and valves, epicardial border identification, processing time. Finally, the matching between the automatic border tracing and the true anatomical border, extracted by an expert, is analysed.

Key words: Medical Image Processing, Ultrasound Imaging, Segmentation.

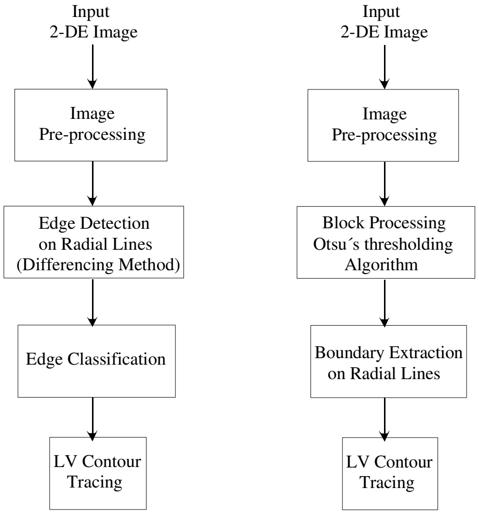
A. Introduction

Echocardiography is a valuable non-invasive tool for imaging the heart and surrounding intrathoracic structures and is an essential way to diagnosis heart diseases. It is important to recognize, however, that echocardiographic examination is only a part of the complete cardiac work-up. Two-dimensional echocardiography images (2-DE) are used to evaluate cardiac chamber size (especially the left ventricular one), wall thickness, wall motion, valvular anatomy, valve motion, the proximal great vessels and the pericardium. The most common echocardioghafic views and the recommended standards models and methods [1], for quantitative analysis of cardiac performance are based on the segmentation of the LV cavity and its centroid from end–systolic and end-diastolic frames or from the frames recorded in a complete cardiac cycle. Automatic LV segmentation is a difficult task due to the relatively poor quality of echocardiografic images where the speckle noise is the main degradation mechanism. Some artifacts like papillary muscles, intra-cavity structures as chordae, and valves can also interfere with the endocardial border tracking. Image-based LV contour extraction can, in general, be classified in three main groups, according to the processing strategies used. Namely, edge-based, radial search-based and sequential frame-based strategy. The first two approaches extract LV boundaries in a sequence that begins with image pre-processing followed by edge detection, edge classification and edge linking and contour defining. An important difference between them occurs at the level of the edge detection phase. In the first one the general edge operators are used [2]; in the second the LV boundary edge extraction is based on the intensity profile analysis along each radial line emerging from the region centre to be segmented [3, 4]. In the sequential frame-based approach the LV epicardial or endocardial boundaries are previously located in the first frame or the frames corresponding to end-systole and end-diastole, by an expert. The initialised LV boundaries are then mapped to the next frame in order to define the new regions of interest in that frame. The process is repeated for the entire image sequence [5, 6]. In this work, we use two different techniques to track the LV boundaries. First, based on the radial search-based approach the intensity profiles along each radial line are analysed by a differencing algorithm. Second, an approach by windows adaptive thresholds is implemented using the Otsu's method. In section II, we present the two mentioned techniques, specifying their algorithms in terms of flow charts. The results provided by the two techniques are shown in section III. Some discussion is also presented concerning to the usefulness and accuracy of the techniques in LV border tracing. The correlation between the automatic border tracing and the true anatomical border, extracted by an expert, is also analyzed.

B. Methods

B.1. The differencing algorithm

The differencing algorithm is one-dimensional first derivative operator applied to each intensity profile along to the radial lines. Radial lines emanate from centre to outward. Boundary search is made along each radial line. This approach has the advantage of reducing the boundary searching work to one dimension which is very important in reducing the processing time. Also, the edge detection on radial lines produces better edge estimates. In our study, the centre of the LV cavity is identified manually by an expert operator, though; this could be made automatically [7]. The differencing algorithm application is composed by three important stages: image pre-processing, boundaries extraction, and knowledge based contour following, as represented by the block diagram in figure 1(a). Pre-processing of images includes both data size reduction and image enhancement. Data size reduction takes place in two distinct steps. First the active echo cone (the echocardiographic image itself) is separated from the rest of the picture that in general have patient identification and the information regarding to the set-up of the echo system.



(a) (b)

Fig.1. General block diagrams of (a) the differencing edge detection; (b) Block processing by Otsu thresholding algorithms.

Second, images are led to a fixed size (for instance 350 x 350) to represent well the LV Region of Interest (RoI)). This task allows a substantial reduction of the computational time, helping to achieve the long term goal of real time automatic LV assessment. The RoI size can be redefined according to the different configurations of the echocardiography devices. Image enhancement involves, in general, image smoothing to reduce the high level of noise in the 2-DE images, and image histogram modification manipulated by the more frequently used background subtraction and linear contrast stretching techniques. Space domain image smoothing is the most common procedure for noise reduction in 2-DE [3,8]. In this approach each pixel value is replaced by a linear or nonlinear combination of all pixel values in the neighbourhood. Nonlinear spatial domain filtering, like median filters, give rise to more effective noise reduction and less blurring effect, however, this approach is time consuming, thus, restricting the goal of real time assessment. Image histogram characterises the frequency of occurrence of grey values. Then, modifying the histogram some image features like endocardial or epicardial boundaries can present an improved contrast. Background subtraction is a simple technique where the greyscale image is subtracted from a fixed value. Pixels with negative results are set to zero. The fixed value, in general, is a fraction of the maximum grey value in the image or could be the mean grey value of the RoI. In the linear contrast stretching technique, the grey value of each pixel is multiplied by a constant. If the new pixel value is greater than the maximum acceptable value, it is replaced by the maximum. This gives rise to a linear expansion of the greyscale and produces a histogram that is wider than the original one.

B.2. Windows adaptive thresholds by Otsu algorithm

We propose an alternative LV boundary extraction technique which is based on image processing by windows adaptive thresholds using the Otsu algorithm. The block diagram is shown in figure 1(b). Comparing the block diagrams shown in figure 1, there are some common basic image processing procedures, where the most important one is the pre-processing. The method consists of dividing images into rectangular blocks, and performing some operation on each block individually to determine the values of the pixels in the corresponding block of the output image. For each block a threshold is obtained using the Otsu's method. Formulated as discriminant analysis, the method separates pixels into two classes (objects and background), by a threshold. The criterion function involves between-classes variance (σ_b^2) to the total variance (σ_t^2), and is defined as:

$$\eta = \frac{\sigma_b}{\sigma_t}$$

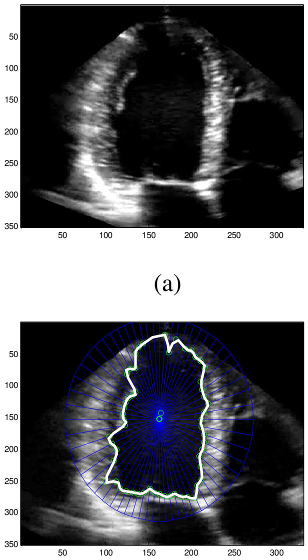
All possible thresholds, through each selected block are evaluated in this way, and the intensity that maximizes this function is the optimal threshold [9]. The optimal size selection for blocks (12, 150), were found after some previous tests. The resultant binary image allows a clear discrimination between LV cavity and the myocardium walls, which makes the contour tracing much easier. To this end, first an initial point should be identified. A simple way consists of scanning a line in the image that crosses the LV wall from one side to the interior of the cavity. The last nonzero pixel found in the transition from the wall to cavity is the initial point on the object boundary. This procedure is reliable only if the LV cavity is clear. Contour tracing in binary image is accomplished considering nonzero pixels belonging to the object and "0" pixels constituting the background. The cubic spline interpolation was then used to smooth the LV extracted boundaries.

C. Results and discussion

Several frames extracted from a cardiac cycle corresponding to apical long axis four chamber views were used in this work. Figure 2(a) illustrates one of those frames after data size reduction and histogram modification. Figure 2(b) shows the endocardial boundary extraction for a frame in systolic stage using the differencing algorithm.

To reduce the computation time, an ellipse [7] was considered over the LV region, and the boundaries were extracted on the radial lines emanating from the ellipse centre coincident with the LV one. In this work, sixty radial lines were used although a smaller number could be selected without significant lost of accuracy, with a corresponding processing time reduction. As mentioned before, segmentation by block image processing using Otsu thresholding gives rise to a binary image from which a mask for the LV can be easily extracted.

This mask was then object of an additional processing by performing morphological image closing in order to hide the presence of the papillary muscle (see figure 3(a)). The application of the procedure mentioned in section B.2 to boundary extraction, have produced the results shown in figure 3(b). Contour tracing is also illustrated as a result of interpolation by cubic spline curves. The contours shown in figures 2(b) and 3(b), provided by the two implemented techniques, are essentially different in the region of the papillary muscle.

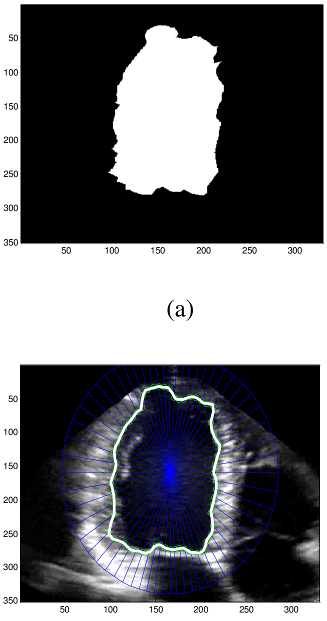


(a)

(b)

Fig.2. (a) Left ventricular cavity of a 2-DE image; (b) Boundaries extraction by differencing technique and contouring by cubic spline curves.

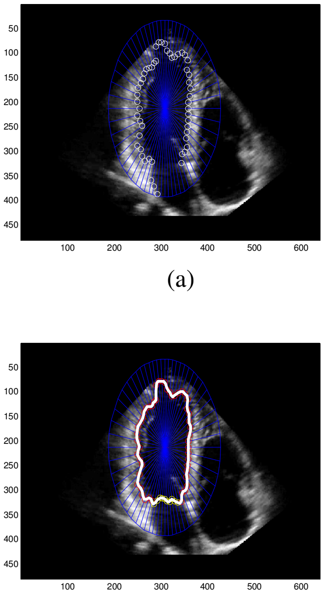
Besides, the segmentation by block image processing using Otsu thresholding with LV mask extraction leads to higher smooth and continuous contours. Boundaries from the differencing technique, as observed in figure 2(b) are inconsistent needing more additional processing to remove erroneous edge points or to avoid some artifacts like papillary muscle. Additionally, boundaries extraction in the mitral valve region is imprecise using the differencing method and not possible by block image processing (see figure 4(a)), when the valve is opened. To solve this problem, we considered that the mechanics of LV in the valve region is not altered significantly along with the cardiac cycle. This was confirmed by a cardiac technician who, in general, connects the cavity walls by a straight line. Thus, whenever the ventricle is in the diastolic function, the LV contour in the mitral valve region was automatically closed considering the corresponding boundaries extracted from LV in the systolic function, as shown in figure 4(b). To evaluate the accuracy of the endocardial border extraction using the Otsu thresholding algorithm, the images were analysed by a skilled technician in order to identify the true boundaries.



(a)

(b)

Fig. 3. (a) LV mask without papillary muscle; (b) Boundary extraction and contouring by cubic spline curves.



(a)

(b)

Fig.4. (a) Boundary extraction for the LV in diastolic function (valve opened); (b) Contour definition in the valve region considering LV boundaries extracted in the diastolic function.

Due to the lack of information in the apical region verified in all images the expert was unable to follow correctly the contour. Thus, the tracing was made based on his expertise. Figure 5 illustrates the border points extracted by the block processing technique using the Otsu thresholding algorithm (crosses), and the ones marked by the technician (circles) for an easy correlation.

Assuming the contour marked by the expert is of acceptable confidence, it is observed a high similarity degree between the two results concerning to the endocardium walls. Little mismatch can be observed in the region of mitral valve, which can be explained by the fact that technicians assume a straight line as a way to close that region. Greater mismatch, however, is observed in the apical region. The prime reason for that is the inadequate information in the images that makes difficult a correct extraction of boundaries even by an expert. Some improvements in image tracking in order to enhance that region could give rise to better extracted boundaries.

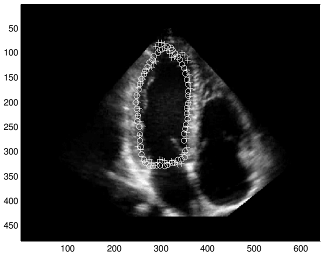


Fig.5. Results of automatic segmentation by Otsu thresholding algorithm (crosses) versus markings made by the techinician (circles).

It is well known that quantitative measurement of cardiac function is closely related to the left ventricular function. Important factors like ejection fraction, regional LV wall motion and LV wall thickness have proved to be clinically very useful. Considering the last factor, it is clear that the epicardial boundaries should be extracted. One possible approach to calculate the myocardial wall thickness is based on the following: for a given point localized in the myocardium boundary (endocardium or epicardium), the wall thickness corresponds to the nearest point on the other side of the myocardium boundary. Again the windows adaptive threshold procedure by Otsu algorithm seemed to be very effective to extract the epicardium border as illustrated in figure 6. Some additional image processing was accomplished to eliminate the artifacts associated with the other cavities, and smooth the contours. The LV cavity contour clearly approaches to that provided by the technician.

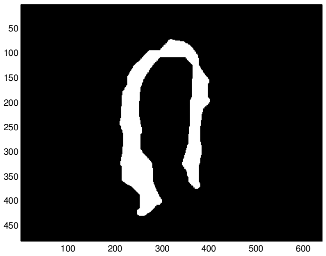


Fig.6. Long-axis LV image at diastole after some morphological operations.

D. Conclusions

Two different approaches were used in this work to automatically extract LV cavity contour from 2-DE images: edge detection on radial lines by the differencing technique and windows adaptive thresholds by Otsu algorithm. A sequence of frames along a cardiac cycle was considered. Particular relevancy was given to those coincident with end-systole and end-diastole. Results demonstrated that the windows adaptive threshold procedure is more effective and robust for LV boundary extraction. The exception deals with the contour tracing in the mitral valve region when the LV is in the diastolic function. The knowledge that the LV does not suffer important geometrical and morphological changes in this region provided a solution to the problem, which consisted of using the corresponding boundaries extracted from LV frames in systolic function. Considering that technicians use a straight line to close the mitral valve region, that approach is clearly acceptable. Results also showed the windows adaptive threshold procedure can handle more easily the problems associated with the LV artefacts like papillary muscles. The endocardial extracted boundaries are continuous and smooth. Additional important information like myocardial wall thickness can be extracted with this technique in a simpler way compared with the edge detection on radial lines using the differencing method. The knowledge of the LV cavity centre is not strictly necessary with that technique.

E. Acknowledgements

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F. References

[1] N. B. Schiller,"Two-dimensional echocardiographic determination of left ventricular volume, systolic function and mass".Vol. 84 ([suppl I]), pp. 280-287, 1991.

[2] G. Coppini *et al*.,"Recovery of 3-d shape of the left ventricle from echocardiographic images", *IEEE Trans. on Med. Imag*., Vol. 14, Nº 2, pp. 301-317, 1995.

[3] N. Friedland and D. Adam, "Automatic ventricular cavity boundary detection from sequential ultrasound images using simulated annealing", *IEEE Trans. on Med. Imag*., Vol. 8, Nº 4, pp. 344-353, 1989.

[4] S. K. Setarehdan, and J. J. Soraghan, "Cardiac Left Ventricular Volume Chnages Assessment by Long Axis Echocardiographical Image Processing", *IEE Proceedings-Vision, Image and Signal Processing*. Vol. 145, nº 3, pp. 203-212, 1998.

[5] V. Chalana *et al*.,"A multiple active contour model for cardiac boundary detection on echocardiographic sequences", *IEEE Trans. on Med. Imag*., Vol. 15, Nº 3, pp. 290-298, 1996.

[6] L. Zhang and E. A. Geiser," An effective algorithm for extracting serial endocardial borders from 2-d echocardiograms", *IEEE Trans. on Med. Imag*., Vol. 31, Nº 6, pp. 441-447, 1984.

[7] J. S. Suri *et al*., "Advanced Algorithmic approaches to medical image segmentation", Springer-Verlag London Limited 2002.

[8] Chia Yu Han *et al*. , "Knowledge-Based Image Analysis for Automated Boundary Extraction of Transesophageal Echocardiographic Left-Ventricular Images", *IEEE Trans. on Med. Imag*., Vol. 10, Nº 4, pp. 602-610, 1991.

[9] N. Otsu, "A Threshold Selection Method from Gray Level Histogram," *IEEE Trans. Systems, Man., and Cybernetics*, vol. SMC-8, pp. 62-66, 1979.