The importance of the pre-processing on the echocardiographic images for the Left Ventricular contour extraction.

J.B. Santos [a], D. Celorico [a], J. Varandas [b], J. Dias [b]

[a] Department of Electrical Engineering and Computers, Institute of Science and Materials Engineering, University of Coimbra, polo 2, 3030-290 Coimbra, Portugal
[b] Department of Electrical Engineering and Computers, Institute of Systems and Robotics, University of Coimbra, polo 2, 3030-290 Coimbra, Portugal

Abstract

The extracting of the contour from two-dimensional echocardiographic images (2-DE) of the left ventricle (LV) has been a difficult digital image processing problem. This is essentially due to the images have very low-spatial resolution, high level of speckle noise, and, some artifacts like papillary muscles, intra-cavity structures as chordae, and valves that can interfere with the endocardial border tracking.
Image pre-processing is an important phase of the segmentation procedure, which goal is to enhance the real boundaries between LV cavity and myocardium. Data size reduction either by Region of Interest defining or by image decimation; image smoothing; background subtraction and linear contrast stretching are the most common enhancement techniques.
In this work we analysis the importance of each 2-DE image pre-processing procedure. Factors like image processing time and improved boundaries extraction are considered in this study as the most important to a real-time three-dimensional LV visualisation.

1. Introduction

Clinical assessment of the left-ventricular (LV) function is essential for evaluating the heart function of a patient with known or suspected heart disease. LV function is normally assessed by two-dimensional (2-D) cardiac ultrasound imaging (echocardiography). Automated analysis of echocardiographic images is challenging because noise and artefacts make feature detection and tracking difficult.
Tracing of the epicardial and endocardial boundaries of the left ventricle (LV) on echocardiographic images is of primordial importance for quantification of cardiac function [1]. Contour tracing on the end-diastolic (ED) and end-systolic (ES) images allows the computation of clinically important measures such as ejection fraction and regional wall thickening. Also, border tracking on all images covering the entire cardiac cycle allows quantitative interpretation of LV dynamics [2]. Manual tracing of these borders requires an expert and besides, is a time consuming and labour intensive task, when lots of images need to be analysed.
Automatic boundary extraction from echocardiographic images thus, appears as a clinical important need to produce most effective and reliable results. In spite of many researchers have attempted to identify the LV boundaries on 2-DE images, automatically or semi-automatically [1,3,4,5], this goal still is a challenge. Limited clinical applicability of these methods is related to the poor quality of the images with the consequent low contrast at the boundaries or even boundary discontinuity in some frames. Almost all approaches for LV boundary extraction use some common image processing procedures, the most important ones being pre-processing and edge detection. The aim of this work is to provide a review of the application of the image

pre-processing techniques. Some factors like the level of pre-processing and the computational time necessary to achieve an improved and effective boundary tracking, will be analysed. Manually defined LV borders will also be compared to the ones resulting from the different pre-processing approaches. The boundary extraction was based on radial search-based strategy, i.e., on the intensity profile analysis along each radial line emerging from the region centre to be segmented [1,6,7,8].

2. Pre-processing techniques of 2-DE

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. In our case a fixed size of (400 x 400) was considered 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. These are applied to the image Region of Interest.

2.1. Image filtering

Space domain image smoothing is the most common procedure for noise reduction in 2-DE [8,9,10]. In this approach each pixel value is replaced by a linear or nonlinear combination of all pixel values in the neighbourhood. In linear space domain filtering, each pixel in the smoothed image g(x,y), is obtained from the average pixel value in a neighbourhood of (x,y) in the input image *f*:

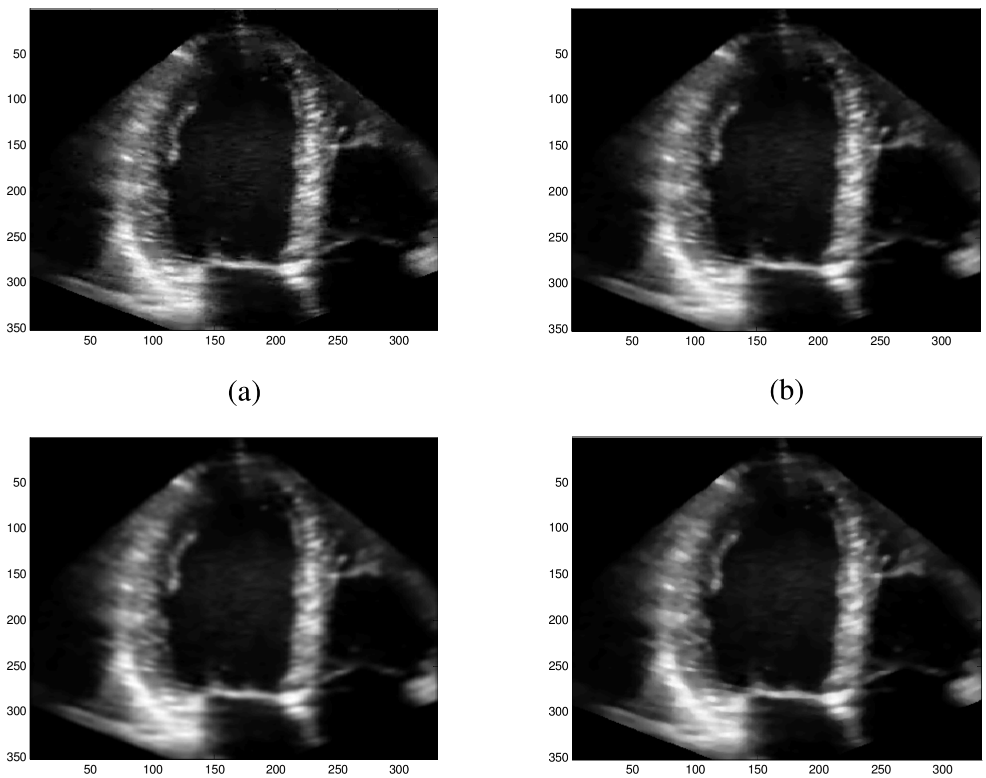
$$g(x,y) = \sum_{i,j=-m}^{m} W(i,j).f(x+i,y+j) \qquad (1)$$

where, *W* is called the convolution kernel. For instance, if we use a 3x3 neighbourhood around each pixel the mask could be the following:

$$\frac{1}{9}\text{x} \begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array} \qquad (2)$$

Each pixel value is multiplied by 1/9, summed, and then the result placed in the output image. This mask is successively moved across the image until every pixel has been covered. That is, the image is *convolved* with this smoothing mask (also known as a spatial filter or kernel). However, one usually expects the value of a pixel to be more closely related to the values of pixels close to it than to those further away. This is because most points in an image are spatially coherent with their neighbours. Accordingly, it is usual to weight the pixels near the centre of the mask more strongly than those at the edge.

The larger the kernel size, the more noise reduction will be obtained with the corresponding increase in blurring effect. Thus, the degree of such effects can be controlled either by changing the convolution mask or by using adequate weights to the pixels.
Figure 1 illustrates the explained theory. An example of a data reduced image showing the Region of Interest for the left ventricular cavity in a Long-Axis (LA) view is shown in figure 1(a). Linear filtering was applied to the same image using a (3x3) window size (see figure 1(b)), and a (5x5) window size (figure 1(c)). It is apparent a higher noise reduction applying the (5x5) filtering with a subsequent increase in blurring effect and computational time.



(a) (b)

(c) (d)

Figure 1. (a) Left ventricular cavity of a 2-DE image; (b) same image after smoothing with a (3x3) window size; (c) same image after smoothing with a (5x5) window size; (d) median filter application using a (5x5) window size.

Nonlinear spatial domain filtering, like median filters, give rise to more effective noise reduction and less blurring effect [11], however, this approach is time consuming, thus, restricting the goal of real time assessment. Figure 1(d) illustrates the result of median filter application using a (5x5) window size. The main disadvantage of median filtering in a rectangular neighbourhood is its damaging of thin lines and sharp corners in the image. This can be avoided if another shape of neighbourhood is used.

2.2. Histogram modification

As mentioned before, the other approach for image enhancement applied to 2-DE is histogram modification [11,12]. Image histogram characterises the frequency of occurrence of grey values. Thus, modifying the histogram some image feature 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 [13]. 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. The 2-DE image shown in figure 1(a) is now represented in figure 2(a) after histogram modification: background subtraction and linear contrast stretching. The modified histogram is shown in figure 2(b). The minimum grey value in the image was used as the background.

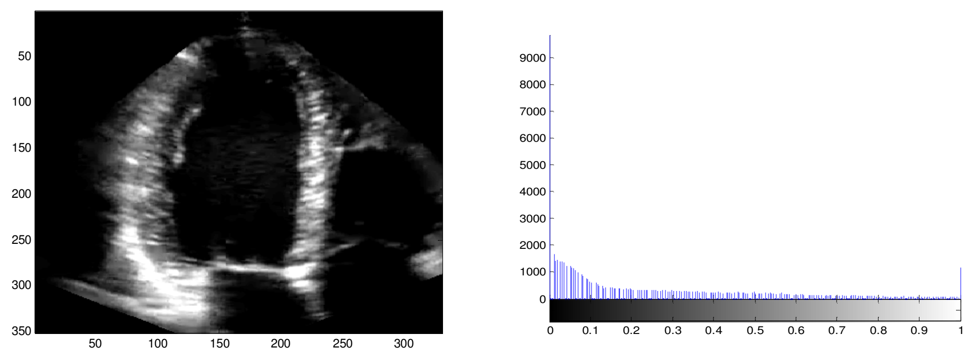
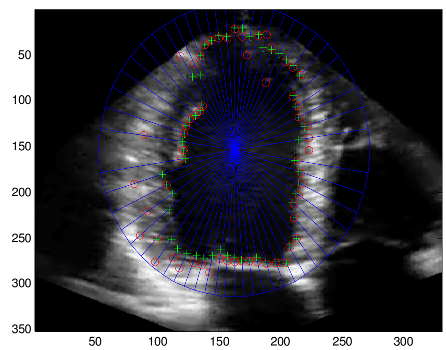


Figure 2. (a) The 2-DE image (figure 1(a)), after histogram modification, (b) its histogram after modification.

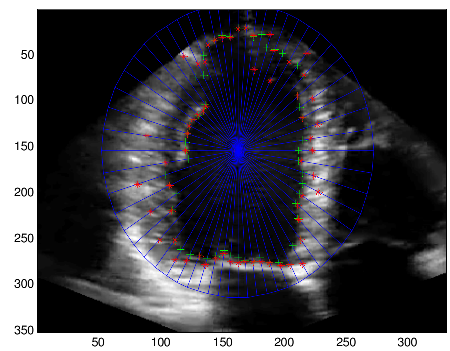
3. Pre-processing effect in the LV boundary extraction.

The radial search-based strategy was used to extract the boundary contour. Radial lines emanate from centre to outward. Boundary search is 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 was identified manually by a physician. The boundary extraction was performed considering images with and without some pre-processing.

Figure 3(a) illustrates the boundary extraction using a differencing algorithm. The differencing algorithm is one-dimensional first derivative operator applied to each intensity profile along to the radial lines. Any point where the derivative is a local maximum is a potential edge. Boundaries represented by crosses were obtained using images after histogram modification. Circle border points are the result of using linear filtering. The analysis of figure 3(a), suggests that the image enhancement technique is very useful to an effective LV boundary extraction. On the contrary, the linear smoothing operation alone seems not to produce good results. Figure 3(b) shows the boundaries from histogram modification (crosses) and nonlinear filtering by median filters (asterisk). It is apparent that the image pre-processing by median filtering does not contribute greatly to acceptable boundaries besides being a time consuming technique.



(a)



(b)

Figura 3. (a) Boundaries from histogram modification (crosses), and linear filtering (circles); (b) boundaries from histogram modification (crosses), and median filtering (asterisk).

4. Conclusions

In this work we demonstrated the importance of the pre-processing on the echocardiographic images for boundaries extraction of LV. Image smoothing using linear filtering (kernels of different sizes) and nonlinear filtering (median filtering), and image histogram modification by background subtraction and linear contrast stretching techniques were compared and evaluated in terms of their importance for an effective and reliable left ventricular contour extraction.

As expected, both linear and non-linear filtering leads to noise reduction which increases with the convolution kernel size. However, the images become blurred thus affecting the eventual anatomical features extraction. Median filtering reduces blurring of edges but it not attractive because of the higher processing time. Important image improvement is achieved using histogram modification. By choosing the minimum grey value in the image as the background, this process extends the histogram of the input image over the entire range of possible grey values.

Finally, the relevancy of the different image processing techniques was put in evidence making the boundary extraction of the left ventricle. The procedure consisted of using a differencing algorithm applied to each intensity profile along to the radial lines. As demonstrated, the boundaries appear better defined for images enhanced by histogram modification than for the ones previously smoothed by linear or non-linear filter application. Also, there is no appreciable advantage in the boundary extraction process when one use smoothed images compared with those without pre-processing.

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