AUTOMATIC LEFT VENTRICULAR CONTOUR EXTRACTION FOR VOLUME CALCULATION FROM ECHOCARDIOGRAPHIC IMAGES

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This paper presents a new fully automated algorithm that extracts LV epicardial and endocardial borders from 2-D echocardiograms. The method is based on a radial search approach, which is the best way to use some a priori informations of the edges. A signature descriptor of contours is carried out. From that function and using Fourier series for extrapolation and tracking in some steps a good approach of edges is found. an extension of this algorithm to contour searching on a sequence of 2-D echograms covering the entire cardiac cycle is easily performed. From this approach over apical rotatied views a cylindrical integration method is used for estimating the left ventricular volume.

INTRODUCTION

Practically the complete set of parameters to be extracted automatically from echocardiographic images can be attained easily once the walls of the carities to be analyzed. The great advantage which the use of non-intrusive methods offers is offset by a poor signal/noise ratio which can be enough for a qualitative analysis, but it make very difficult to carry out a parametric survey of cardiac structures.

Due to the importance of getting a good contours approach for quantitative anaylsis from 2-D echocardiac images, a great amount of effords have been developed. Although general methods for edge detection can be applied quiet succefully in some cases [1], do not allow general fully automatic determination of the correct contours of the structures to be analyzed. Thus, a specific method for the analysis of this type of images had to be developed.

Perhaps, the main characteristics, such as their shape, size, separation between walls and other factors for which normal

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values are aproximately known, would also have to be included.Visual analysis also provides information on other characteristics which aid in contour searching. Examples include the noticeable gradient that exists on passing from inside a cavity, where there is low backscattering, to the wall, and the high reflection of the epicardium. The best way of incorporating all these known characteristics in contour searching was be doing a radial analysis. This procedure has been used in other studies to calculate the separation between walls and to follow the movement of these [3].

The algorithm, which has been developed for the aforementioned analysis will be explained for external contour, for the sake of simplicity. Further results using other images, such as aplical views, have been obtained succesfully as well. It should be pointed out that the lateral sides of the original 512x512 image have been eliminated since they do not carry contour information. The resulting 256x256 image was then used to speed calculations.

ALGORITHM

Transformation into polar coordinates. Calculation of the center.

In order to carry out the radial analysis, the first step involves choosing the new center of coordinates in the interior of the cavity whose wall contours are being searched. Echocardiographic images can be divided into two types : a) those which mainly show one cavity, with a certain circular symmetry (parasternal views), b) those which show various cavities, some of which do not display closed contours. If this point is considered, adding the fact that images have very low SNR, it means that classical methods for obtaining geometrical atributes, such as mass centers, moments, are not in general directly applicable. It has been possible to obtain the average center of the cavities through the application of certain classical tools, along with the introduction of intelligent information of the image to be treated.

In the short-axis view the center is the point most frequently equidistant to the points which belong to the walls of the cavity. Based on that, a procedure for finding the radius and the center of the left ventricle has been developed, with three stages : a) Pre-processing of the image (low-pass filtering elimination of isolated points) and binarization, b) construction of a table of equidistances. c) the average center C_m is selected as the point which with greatest frequency is at the same distance R_m from the rest of the points.

In order to estimate cavity centers in echocardiograms which display more cavities, the number of cavities to be detected is introduced as a parameter. After the binarization, the cavities are detected by a horizontal and vertical sweep, definying segments. Mid-points for each segment are calculated, which are classified into n groups by analyzing the x and y coordinate distributions of the horizontal and vertical segments respectively. An estimation of the centers of the cavities is obtained from the x and y mean values in each class.

Once the center coordinates is chosen, the following step is the transformation of the information into polar coordinates by going from $I(nx_o, my_o)$ to $I(k\rho_o, l\theta_o)$. Although there are various solutions for interpolating, we have decided to use a bilinear interpolation due to the compromise between quality and computational cost.

Distance Function

The basis of the contour search algorithm is what we call the "distance function" $f(n)$ (or $f(n\theta_o)$). In fact, it is nothing more than a signature. It means the value of ρ ($\rho = N\rho_o$) or the number of pixels N between the center and some characteristic determined for each radius $\theta = n\theta_o$.

The starting point of the algorithm is the use of a special characteristic of the contour points over those points which do not share this characteristic. Whether analyzing the image visually, one can think of a marked gradient for the detection of the interior contour and this is a characteristic which may be used for the internal. Although for the external contour case it is not as visually evident, it can be seen representing $(n\rho_o, \theta)$ that the characteristic to be used is the maximum value of each radius.

t should be pointed out that this function is always $f(n) \geq 0$ for all n. Another characteristic is that a very circular contour causes a flatening of the contour if the center of the coordinates coincides with that of the symmetry. Also, the distance function is periodical.

velopment of the algorithm from the Distance Function

ce the first approximation of the distance function is found (figure 1), the algorithm is made up of a set of routine for scriminating which points of this function belong to the ntour and which do not. To do this, successive appromations e generated until the contour, or rather its correct distance nction, is generated.

first step is determining, from the filtered distance ction, a first span of what can be determined to be the true tour in order to be able to follow the contour points from s first span. In fact, we will base this on that the ction to be obtained is continuous, periodic and with many tinuos derivatives, that is, very smooth. The process of ecting the best span is done through the extrapolation of h span along the whole range of the function and selecting span which gives the least square error. The extrapolation performed by Fourier series approach. What is done then, is to use the extrapolation provided by f(n) in order to search for the contour points close to it. Once all correct spans have been incorporated, using the best Fourier series approximation, new possible points belonging to the contour are searched by means of the same characteristic that had been selected at the begining. In figure 1, the final result superimposed to the initial distance function is shown. In Figure 2 the external contour obtained through this procedure is shown superimposed on the image.

APPLICATIONS OF THE ALGORITHM RESULTS

Sequential searching

Although the procedure that has been described is applied in static case, it can be a powerful tool to the sequential searching of cardiac contours. The fact of knowing the approximate location of the contour allows to apply the real contour points identification criteria to a restricted area around the previous estimation. In this way, the interference due to other cardiac structure such as papillary muscles or valves, or even that of the outer contour which searching the inner contour or viceversa, is avoided during the process of detecting the points that belong to the target contour. From one image extracting an approximate contour and assuming linear displacement over each radii, a good and fast sequencial tracking for the whole cardiac cycle has been obtained [2].

Volume computation

From the apical views, using the described algorithm, the edge of the left ventricle is obtained (figure 3). Different images of tridimensional body are available through the apical rotation technique. It is assumed that the planes are equally spaced by an angle of α degrees.

Various approaches could be used to estimate the volume from these M planes. A volume integration in cylindrical coordinates form the M continues has been carried out succesfully. The first thing it has to be done is to express the surface obtained by the algorithm in cylindrical coordinates (r, θ, z). From those planes the volume can be estimated by

$$V \frac{2p}{2M} \sum_{i=1}^{2M} g(q_1) \qquad (1)$$

where $g(q_1)$ is given by

$$g(q_1) = \sum_{j=0}^{N-1} 1/2 \; [\, r \; (q_1, z_j)]^2 \; \Delta z \qquad (2)$$

This is a simple technique, and it seems to provide accurate estimations of the volume.

CONCLUSIONS

The most outstanding conclusion to be drawn from the present paper is that an automatic quantitative analysis is feasible from 2-D echocardiographic images. The method is easily extended to other echographic views, including the apical planes from which volume measurements can be calculated by means of integration in cylindrical coordinates.

Another aspect that it should be pointed out is the extension of this method to a sequence of the cardiac cycle. Using the algorithm to find the first contour, the same radial method provides a tracking of the moviment of the cavity walls.

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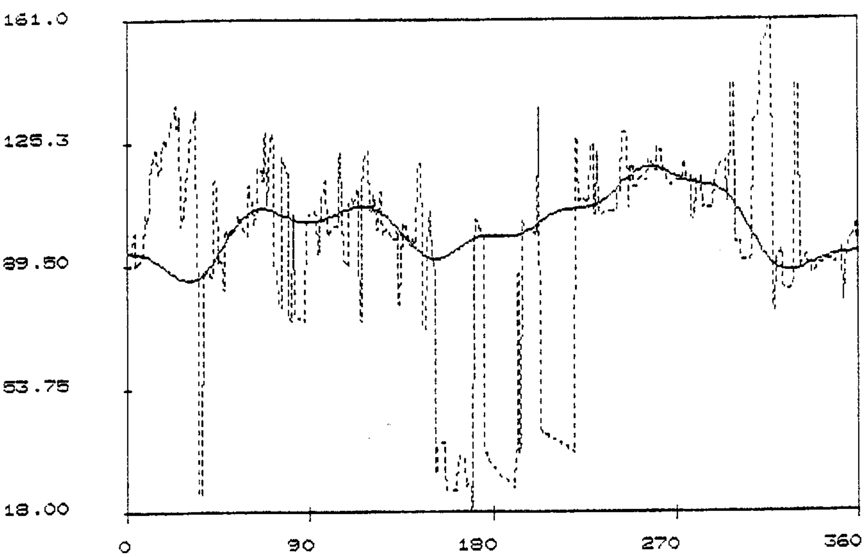

Figure 1.- Inicial distance function between the origin and the absolute maximum on each radii (dashed line). Final result of the algorithm (continuous line).

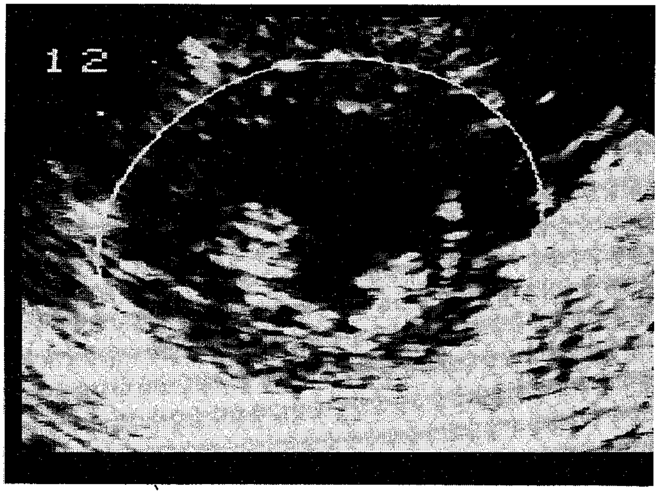

Figure 2.- Final external contourn found.

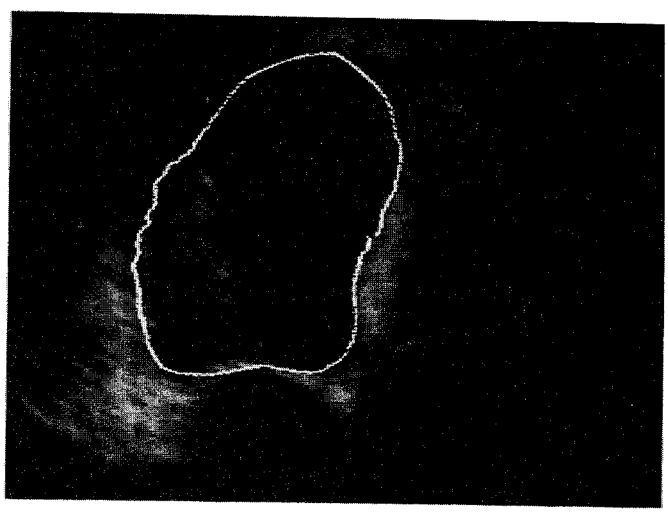

Figure 3.- Result obtained for LV apical view.