A SPATIO-TEMPORAL SEGMENTATION TECHNIQUE FOR THE EVALUATION OF THE MOVEMENT IN DYNAMIC ANGIOSCINTIGRAPHIC IMAGES.

Sandra DENASI*, Giorgio QUAGLIA**

* Istituto di Medicina Nucleare. Universita' di Torino. Italy.
** Istituto Elettrotecnico Nazionale "Galileo Ferraris".
Strada delle Cacce, 91 - I-10135 Torino. Italy.

RESUME

L'extraction du contour du ventricule gauche dans une séquence d'images scintigraphiques est pursuivié par l'algorithme A*, qui, en reliant chaque point de l'image á un nœud d'un graphe directionel, recherche ce contour, comme le chemin au coût minimal qui sépare au mieux les points du ventricule des structures environnantes. Un filtrage de Kalman est joint á la recherche euristique, pour obtènir des meilleurs résultats dans l'extimation du chemin. Un critère de segmentation pour le chemin trouvé est proposé, qui partage le contours en six parties ayant un sens anatomique.

SUMMARY

The extraction of the left ventricle (LV) boundary in a sequence of scintigraphic images is performed relating the points of each image to a directional graph and evaluating the boundary as the minimal cost path that better separate the pixels of the LV from those of the surrounding structures. A Kalman filter added to a heuristic search procedure performs a better estimate of the path. A segmentation of the detected boundary is proposed, that divides the boundary in six anatomical meaningful parts.

INTRODUCTION

The automatic analysis of a sequence of scintigraphic cardiac images holds a peculiar importance in the qualitative and quantitative evaluation of the motion parameters of the left ventricle (LV) wall. Owing to the acquisition technique and the stochastic behavior of the physical phenomena, that allow the representation of the cardiac chambers by means of images, each image is characterized by a low signal-to-noise ratio. In the past years different techniques have been developed in order to evaluate the LV boundary. In a previous paper [1] a detection procedure has been proposed, which detects the LV boundary by means of a heuristic search algorithm. This procedure has been applied to each image of the sequence beginning from the end-diastolic frame (figure 1). The obtained results have confirmed the choice of this type of approach, in spite of some hindrances. They are to be related to the blindness of the A* algorithm that always performs the search of the boundary without regarding if a node is more or less affected by noise. Furthermore each image of the sequence can be considered as the time sampling of a periodic phenomenon corrupted by noise in the period and in the synchronization. This paper proposes some improvements to the procedure described in the previous paper. The insertion of two combined Kalman filters, in the space and in the time domain, makes the removal of these disadvantages possible, allowing a more reliable segmentation of the border in anatomical meaningful parts. In addition, some restrictions of the search area have been introduced in order to resolve those sequences where the separation between the both ventricles is insufficient and it is impossible to evaluate the separation between the left ventricle and atrium.
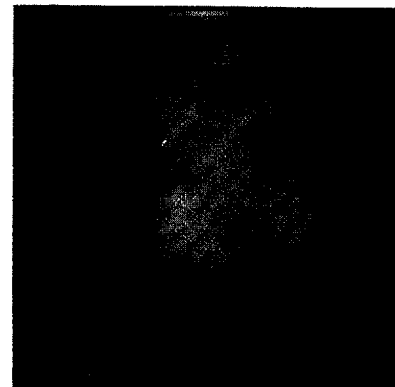

Figure 1 - End-diastolic frame of a sequence of cardiac scintigraphic images.

MOVEMENT INDICATION

The global evaluation of the sequence gives an indication of the dynamic behavior of the cardiac muscle. Two images are calculated, in which the amplitude and the phase of the first component of the Fourier transform of the corresponding points of each image of the sequence are represented. The first one (figure 2a) gives an indication of the amplitude of the changes in volume of each cavity, while the second one (figure 2b) gives a trace of the isochronism of the movement. Since the volume changes of the ventricles occur in phase opposition compared to those of the atria, a separation can be easily performed between these structures.
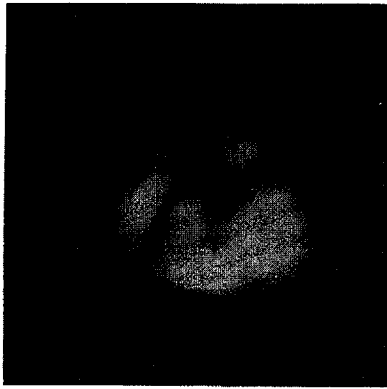
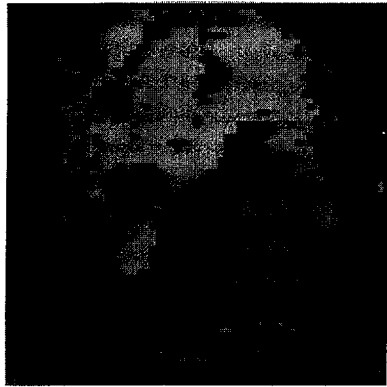Figure 2a - Amplitude image of the Fourier movement representation.

Figure 2b - Phase image of the Fourier movement representation.

Figure 3 - LV search area restriction. A: line that separates atria from ventricles. B: line that roughly restricts the LV area.

SEARCH AREA LIMITATION

Since the LV is a structure that can be easily distinguished in a well known context, the search area can be restricted granting the elimination of the dangerous effects of the neighboring structures. The LV can be located in an angular sector centered on the cardiac shadow and bounded between $\pi/4$ and $-5\pi/8$ radiants.

In order to break down those situations where it is more difficult to discriminate the left ventricle from the corresponding atrium because of the great vessels, the information included in the phase image is exploited. This information can be utilized in order to delimit furthermore the search area by means of the line that separates the two clusters of pixels that represent organs in phase opposition.

Finally, since usually the global border of the heart appears more observable then the border of the LV, in order to make the separation between the two ventricles more distinct, a further restriction has been placed on the search area by cutting out all that points that lie on the left of the perpendicular to the line of separation between ventricles and atria and passing through the centre of the heart (figure 3).
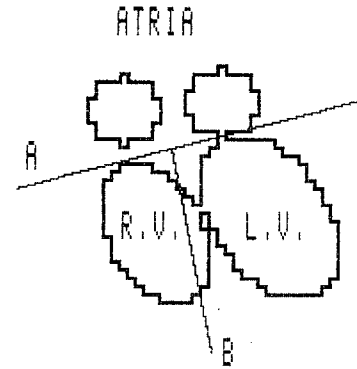
CONTOUR DETECTION

The method carried on for the detection of the contour follows the one already taken on in previous experiences [2,3,4,5]. However, in this situation a more global character has been given exploiting the existing correlation between the images of the sequence.

In each image of the sequence, the contour has been detected as the optimal path in a directional graph, where each node corresponds to a pixel of the image represented in polar coordinates with origin at the approximate centre of the LV evaluated on the average image of the sequence. Each node is linked to the neighbouring nodes by a weighted arc, that is a cost proportional to the second derivative of the signal along the radial coordinate. The optimal path is detected by means of the A* algorithm [6,7]. The costs have been evaluated modifying the search algorithm by means of two Kalman filters [8]: the first one operates inside each frame and the second one operates in the time domain. This solution is suggested because of the different phenomena that rule the image building and of the contour representation, that in space and time follow dissimilar models.

The search begins with the detection of the boundary in the first end-diastolic frame. The introduction of the Kalman filter has modified the A* procedure as it is described in the following. Firstly, many starting points are candidate for the head of a path. For each starting point, all the offspring nodes for the path are investigated in the second row. Each pair of nodes initializes a Kalman filter. In such a way, it is possible to make a first prediction of the position of each successive point of each initialized path using a bank of Kalman filters, one for each hypothesis.

Let $y(n)$ be the true position of a boundary in the row n and $z(n)$ the corresponding measured position. Since the boundary of the LV can be roughly approximated to a circle, its model in the polar representation can be assumed linear and can be represented by a state vector x which evolves with n (level of the graph)

according to the state equation

$$x(n+1) = A\, x(n) + B\, w(n)$$

where

$$x(n) = [y(n)\ \ \dot{y}(n)]^T \qquad \text{State Vector}$$

$$A = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad\qquad B = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

State Transition Matrix   Disturbance Matrix

w(n) = white noise sequence with zero mean
and variance Q (plant noise)

The measurements z(n) are assumed to be related to the state variables x(n) by the equation

$$z(n) = C\, x(n) + v(n)$$

where

$$C = [1\ \ 0] \qquad\qquad \text{Measurement Matrix}$$

v(n) = white noise sequence with zero mean
and variance R (measurement noise)

Each prediction is generated according to the update equations of the Kalman filter:

$$\hat{x}(n+1|n) = A\,\hat{x}(n|n)$$
$$P(n+1|n) = A\, P(n|n)\, A^T + B\, Q\, B^T$$

where $\hat{x}(n+1|n)$ and $\hat{x}(n|n)$ are the prediction P and the estimation E of the state vector x, and $P(n+1|n)$, $P(n|n)$ are the covariance of the prediction and of the estimation errors.

The successor nodes for the next lines are those that lie within a search window centered on the prediction.

Since each measurement is uniquely associated with each path, then the estimation $\hat{x}(n+1|n+1)$, the innovation e(n+1), the innovation variance M(n+1) and the gain of the filter K(n+1) are calculated:

$$\hat{x}(n+1|n+1)=\hat{x}(n+1|n)+K(n+1)[z(n+1)-C\,\hat{x}(n+1|n)]$$

$$P(n+1|n+1)=P(n+1|n)-K(n+1)\, C\, P(n+1|n)$$

$$e(n+1)=z(n+1)-C\,\hat{x}(n+1|n)]$$

$$M(n+1)=C\, P(n+1|n)\, C^T + R$$

$$K(n+1)=P(n+1|n)\, C^T\, [C\, P(n+1|n)\, C^T + R]^{-1}$$

Each node in the window is taken as a measurement Z for the determination of the corresponding estimate. Figure 4 illustrates this procedure.
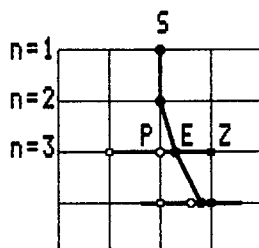

Figure 4 - Search procedure in the graph with the improvement of the Kalman filter.

In the images that follow the first end-diastolic frame, the search procedure is modified in order to include the second Kalman filter. The predicted node is evaluated taking in account not only the history of previous points in the same frames, but also the history of the corresponding points of the boundary in previous frames.

As a consequence, the search procedure is modified according to the following. The first Kalman filter makes its prediction and the proper search window is evaluated; in the same way operates the second Kalman filter. The logical "and" of the two windows becomes the effective search window, within which the successor nodes are looked for.

The procedure, then, carries on as described in the previous section. For the sake of simplicity, a linear model is pursued for this second filter and the equations described above are again efficacious.

SEGMENTATION

Finally, the characterization of physiological meaningful segments in the boundary is performed. Usually, the left ventricle is characterized by four segments: the basal segment in correspondence of the valves at the separation between the LV and the left atrium, the septal segment in correspondence of the separation between the left and the right ventricle, the apical segment, that is the segment that lies bottom right and finally the postero-lateral segment, that divides the external wall from the background.
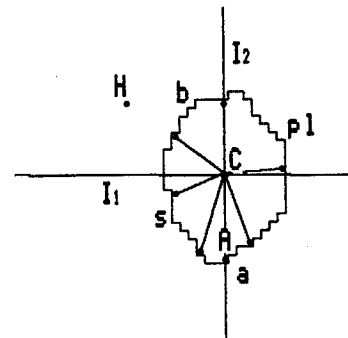

Figure 5 - Segmentation criterion and anatomical sectors.

In order to give a better description of motion, a more precise segmentation is proposed: six segments instead of four are located on the basis of geometrical and shape characteristics. The following procedure is suggested (figure 5): the centre of gravity C of the LV and the principal axes (I1, I2) are determined. The apex A is chosen as the more external point between either the intersection of the axis I2 and the boundary or the farther point from the centre C. The apical segment (a) subtends a sector of 40 degrees around the apex. The marker between the septal (s) and the basal (b) segments is located at the intersection of the boundary and the line passing through the center C and the centre of gravity H of the heart. The bound between the basal segment and the postero-lateral segment (pl) is taken either as the upper intersection of the boundary

with the axis I2 or as the opposite point of the apex in a line passing through the centre of gravity C: the more external point is selected. The septal and the postero-lateral segment are divided in two parts: the upper and the lower one.

The same method is pursued in the successive images. Regularity of motion of the main markers is checked for the whole sequence in order to avoid misleading segmentations around the systolic phase.

CONCLUSION AND RESULTS

The proposed technique has been tested on several sequences of scintigraphic images. The results are very promising. The figure 6 shows the boundary and the proposed segmentation superimposed to the end-diastolic frame. However, some shortcomings remain due to the noise and to the surrounding structures. Sometimes the detected path encompasses both ventricles and in this case the development of a "formal" heuristic search algorithm could improve the outcome, that is, the inclusion in the cost matrix of a term that depends from the shape of the boundary will contribute to the proper detection of the path. The extension to the succeeding images could further be improved performing a three dimensional search algorithm that looks in a 3-D graph.
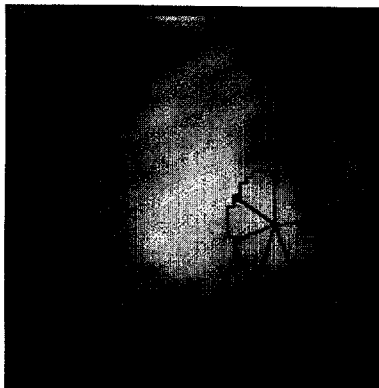

Figure 6 - The detected boundary and the seg-
mentation superimposed to the
filtered end-diastolic image.

REFERENCES

1 - Bo A.; Fubini A.; Quaglia G.: A heuristic search procedure for the automated analysis of dynamic cardiac scintigrams. 12. Coll.GRETSI, Nice, France, 20-24 may 1985, 769-773.

2 - Niemann H.; Bunke H.; Hofmann I.; Sagerer G.; Wolf F.; Feistel H.: A knowledge based system for analysis of gated blood pool studies. IEEE Trans. on PAMI Vol.7 n.3 (1985) 246-259.

3 - Gerbrands J.J.; Hoek C.; Reiber J.H.C.; Lie S.P.; Simoons M.L.: Minimum cost contour detection in tecnetium-99m gated cardiac blood pool scintigrams. Comp. in Cardiol. Sept 1981. 281-284.

4 - Reiber J.H.C.; Lie S.P.; Simoons M.L.; Hoek C.; Gerbrands J.J.; Wijns W.; Bakker W.H.; Kooij P.P.M.: Clinical validation of fully automated computation of ejection fraction from gated equilibrium blood-pool scintigrams. J. Nucl. Med. 24 (1983) 1099-1107.

5 - Elliot H.; Cooper D.B.; Symosek P.: Implementation, interpretation and analysis of a suboptimal boundary finding algorithm. IEEE Trans. on PAMI Vol.4 n.3 (1982) 167-182.

6 - Pearl J.: Heuristics: intelligent search strategies for computer problem solving. Reading(Ma): Addison-Wesley Publishing Company 1984.

7 - Nilsson N.J.: Principles of artificial intelligence. New York Springer-Verlag 1982.

8 - Candy J.V.: Signal Processing: the model-based approach. New York: McGraw-Hill Book Company 1986.