TAGGED CARDIAC MRI : DETECTION OF MYOCARDIAL BOUNDARIES BY TEXTURE ANALYSIS

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ABSTRACT

The noninvasive evaluation of the cardiac function presents a great interest for the diagnosis of cardiovascular diseases. Cardiac tagged MRI allows the measurement of anatomical and functional myocardial parameters. This protocol generates a dark grid which is deformed with the myocardium. Tracking the grid allows the displacement estimation in the myocardium. The work described in this paper aims to automate the myocardial contours detection and the following of the grids of tags on Short-Axis and Long-Axis time sequences, in order to firstly optimize the 3D+T study of the parietal contractions and secondly make possible its clinical use. The method we have developed for endocardial and epicardial contours detection is based on the use of texture analysis and active contours models. Texture analysis allows us to define energy maps more efficient than those usually used in active contours methods where attractor is often based on gradient and which were useless in our case of study. The follow-up of the grid of tags that we have implemented is based on a grid of active contours (B-snakes) which part of the energy is calculated in the Fourier's domain. The results obtained with our method is fully automatic and correct on Short-Axis as well as on Long-Axis sequences, when previous works on cardiac tagged MR images analysis always used manual contours detection.

1. INTRODUCTION

The non invasive assessment of the cardiac function is of major interest for the diagnosis and the follow-up of cardiovascular pathologies. Whereas cardiac MRI only allows to measure anatomical and functional parameters of myocardium, tagged cardiac MRI makes it possible to evaluate the intra-myocardial displacement and thus, allows the analysis of the regional contraction of the myocardium (detection of potential contractible areas within the infarcted area). The acquisition protocol usually used by tagged MRI displays a deformable dark grid which sticks to the contraction of myocardium (Fig.1) on the images of temporal Short-Axis (SA) and Long-Axis (LA) sequences. The 3D+T follow-up of this grid makes possible the evaluation of the intra-myocardial displacement and then could make easier the diagnosis of particular pathologies like ischemia for example.

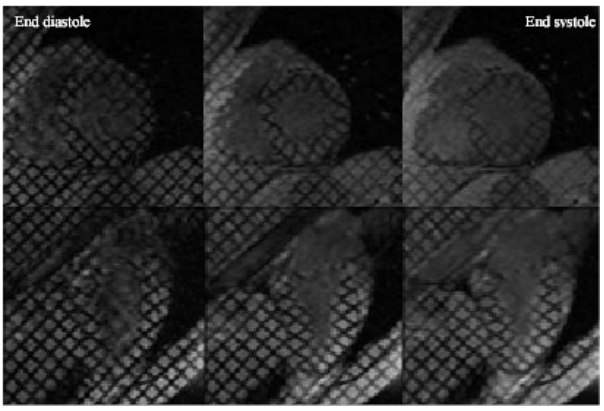


Fig. 1. SA and LA tagged MRI of the Left Ventricle

In a previous article [1] we presented a new method allowing an automatic detection of the grid of tags on SA sequences using active contours. In order to optimize the implementation of the follow-up of the grid near the myocardial contours, we locate the myocardial boundaries (both on SA and LA sequences) to discriminate the points which are within the myocardial part of the Left Ventricle (LV) and then to only follow the displacements of these points. Moreover, for a clinical use of the tagged MRI, we must analyse the 3D+T intra-myocardial displacement. So, the z-deformation of the contraction of the LV given by the LA analysis must be shared with the x-y-deformation given by the SA analysis. The aim of this study is thus to complete the previous study by automating the detection of the myocardial boundaries on temporal SA and LA sequences and by completing the analysis of the grid with the follow-up of the tags on LA sequences. The only study dealing with automatic detection of endocardial and epicardial boundaries was developed by Guttman [2] and carried out on ac-

quisitions radially tagged. After tests, this method turned out to be unadapted to our images. All other works dealing with this detection problem involve manual detection of the myocardial boundaries and manual interventions for the follow-up of the grid of tags [3], [4], [5], and then do not answer to the problem of real automation. As a consequence, we present a new method for detecting the myocardial boundaries which uses active contours and texture analysis. Our method allows an automatic detection of the myocardial boundaries on SA sequences, as well as on LA ones, which is totally new.

2. METHODS

2.1. Active contours

Active contours are able to automatically move to particular data; those which are to be detected. They are geometrically represented and are guided by the following evolution law leading their deformations [6] (equ.1)

$$E(C) = \alpha \int_0^1 |C'(q)|^2 dq + \beta \int_0^1 |C''(q)|^2 dq - \lambda \int_0^1 |\nabla u_0(C(q))| dq \quad (1)$$

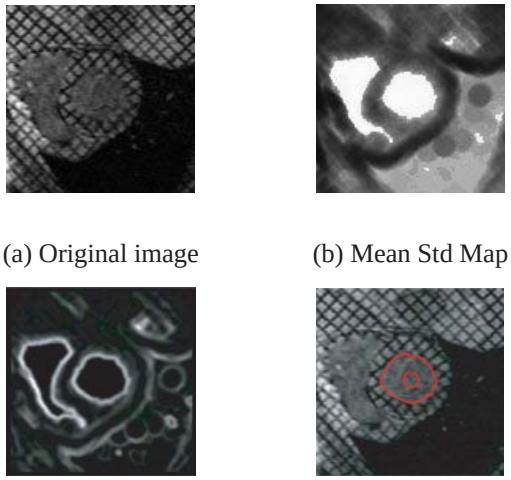
where $C(q)$ is a parametrized flat curve, u_0 the initial image data and α, β, λ are positive constant. The first two parameters α, β control the regularity of the curve (E_{intern}) and λ controls the attraction of the curve to the boundaries of the studied image (E_{extern}). Recently Makowski has presented a new algorithm based on a discrete parametric description of the active contour, associated to the balloon force of Cohen [7] in order to segment the ventricles of the heart and the aorta on MRI images [8]. The method is divided into two different steps. Given an initial contour, a first fast growing (with the balloon force) of the snakes to the boundaries is used to obtain a rough segmentation, which is then used by the second step, during which only the gradient attractor is involved. The first step allows the minimization of the attraction of low gradient (due to stagnant flow) and thus assures the robustness of the detection. In our case, the grid of tags does not allow us to obtain a good gradient attractor for myocardial contours. Without filtering, the gradient underscored the grid of tags, and a strong filtering, which is aimed at erasing the tags, highly smoothes the whole image and makes the gradient ineffective. So we built our own energy maps, adapted to the particularity of tagged MRI. We chose to implement a method directly linked to the one developed by Makowski in order to take advantage of its speed and robustness, but we decided to use a continuous formulation to have a more precise detection. Then the equation which is to be solved for all the following detection can be formulated as follows (equ.2):

$$E(C) = \alpha \int_0^1 |C'(q)|^2 dq + \beta \int_0^1 |C''(q)|^2 dq - \lambda \int_0^1 |\nabla E_{map}(C(q))| dq + \kappa \int_0^1 \vec{n}(C(q)) dq \quad (2)$$

where E_{map} is our energy map and $\vec{n}$ is the local normal of the curve (balloon energy).

2.2. Location and follow-up of the myocardial boundaries on SA sequences

A major property observed on SA and LA tagged MRI sequences, is the fast erasure of tags in the cardiac cavity due to blood circulation. This property leads us to locate and follow endocardium first. With this property, the calculation of a mean-standard deviation map allowed us to build a precise energy map (much better than the usual gradient one) to detect the endocardial boundary (fig. 2c). The algorithm then used in order to follow the movement is directly inspired by (equ. 2) involving a balloon energy to assure the robustness of the initialization and the coherence of the detection (fig. 2d).



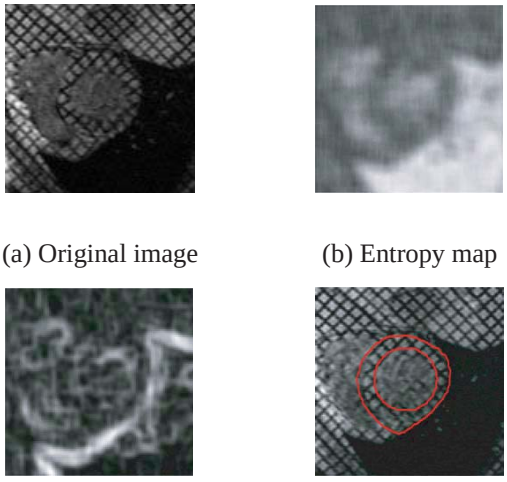
(a) Original image (b) Mean Std Map

(c) Gradient (d) Result

Fig. 2. Detection of the endocardial boundary of the LV using texture analysis

The segmentation of the epicardial contour was more complex to implement (as we can see on fig. 1, the boundary is hard to detect even visually). In fact, two major problems were to be solved: the initial contour must assure a robust detection, and the segmentation can not use the simple gradient of the image as attractor. Thus we have developed a method directly inspired from the precedent one. In order not to be influenced by initialization problem as often

when snakes are involved, we dilate the detected endocardial boundary which detection is not influenced by initial contour (strong energy map + balloon force). This dilatation allows us to obtain the initial coordinates for the detection of the epicardial boundary. In order to solve the second problem, it appeared interesting to analyse the particular texture of the lung. This area, compared with the rest of the image, is described by a rough texture. Thus, the use of second order texture parameters and more particularly, the calculation of the co-occurrence matrix entropy on a 5*5 block, allowed us to reveal the lung area by characterizing it with high entropy coefficient (fig. 4b). The map then obtained allowed us to build an interesting energy map (fig. 4c) to attract our active contours in the same way as the endocardial boundary (equ. 2) (fig. 4d).



(a) Original image (b) Entropy map

(c) Gradient (d) Result

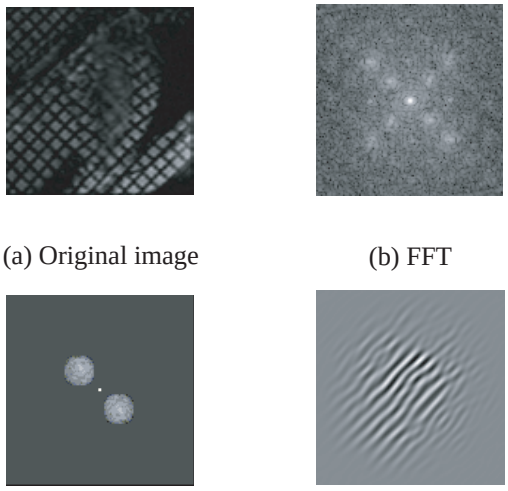
Fig. 3. Detection of the endocardial boundary of the LV using texture analysis

2.3. Location and follow-up of the myocardial boundary on LA sequences

As we have said before, the property of fast erasure of the tags can also be noticed on LA sequences. As a consequence, it seems possible to detect the LA boundary of the myocardium by dividing the segmentation into two steps. The mean-standard map is first used in order to detect the inner boundary delimited by the non tagged cavity, and the texture map calculated from entropy and uniformity parameters allows us to segment the outer boundary by highlighting once again the lung texture. The energy maps are not shown here because of their similarity with the precedent ones. The results of segmentation are presented in the following part of the article (fig. 5,6)

3. FOLLOW-UP OF THE GRID OF TAGS ON LA SEQUENCES

The follow-up of the grid of tags that we have implemented is based on a grid of active contours (B-snakes) which allows us to move only the intersection points and to integrate regularity properties (definition of an internal energy), with a parametric and continuous modelling. The energy E associated to the grid is expressed as the summation of an internal energy E_{intern} which guarantees the regularity of the whole grid, and of an image energy E_{image} whose aim is to have a coherent attraction from the grid of splines to the grid of tags. To assure the resistance of the follow-up of the grid to noise and to the discontinuities of the tags due to the cardiac cavity, we have built E_{image} by a filtering in the Fourier's area (fig. 4b). A filtering in this area, which keeps only the characteristic pics of the grid, and the return to the image area through inverse FFT, is an effective method to obtain specific information of the grid (fig. 4d).



(a) Original image (b) FFT

(c) FFT Mask (d) Result

Fig. 4. Detection of the endocardial boundary of the LV using texture analysis

So, $E_{intensity}$ can be noted as follows :

$$\sum_{i,j}\left(I_s(i,j)+\int I_1(\alpha_{i,j}(u))du+\int I_2(\beta_{i,j}(\nu))d\nu\right) \tag{3}$$

where $I_s = I_1 + I_2$ and $\alpha_{i,j}(u)$ spline arc centered on (i,j) and directed at 45^o and $\beta_{i,j}(v)$ spline arc centered on (i,j) and directed at 135^o

4. RESULTS

As shows figure (5), the detection of the endocardial contour is satisfactory and the implemented method is robust as regard of the initialisation. About the results of the detection of the epicardial contours, the method allows us to obtain satisfying results which are in agreement with medical specialists opinion. The method is less robust than when it is implemented for endocardial segmentation, but still good, and the way we initialize the segmentation allows us not to be too dependant of this important step. The fact that even visually, detection still very difficult for radiologist, is particularly important for the consideration of our results. Moreover, we present here a method which also allows segmentation of myocardial boundaries on LA sequences. The results obtained are satisfactory (fig. 5) and sufficient in order to lead future study on Z-axis about the rotational movement of the LV.

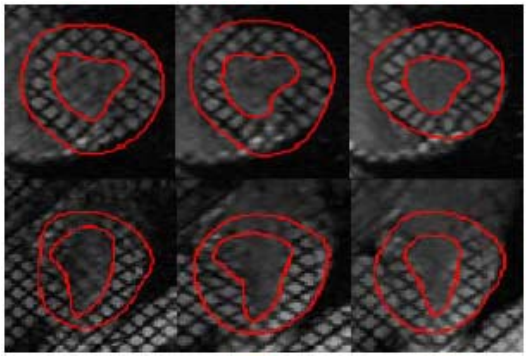


Fig. 5. Contour Detection on SA and LA sequences

Our method to follow the grid of tags on LA sequences gives satisfying results (fig. 6) and is fully automatic.

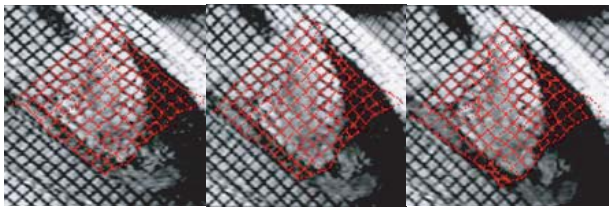


Fig. 6. Tag detection on LA sequences

5. DISCUSSION

The detection of the endocardial and epicardial boundaries on SA and LA sequences is fully automatic and satisfactory, whereas the literature always involves manual detection during the analysis of the tagged MR images. As far as the robustness is concerned, progresses still to be done in the way the segmentation is influenced by the variation of the weight of the different forces which are used. But because the robustness has been proved to be good on 5 different sequences, it is now possible to use those results (shared with those given by the follow-up of the grids on SA and LA sequences) to develop a $3D + T$ analysis of the myocardium. The aim of this study will be the calculation of local quantitative parameters in order to reveal an eventual pathology like ischemia for example.

6. REFERENCES

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