MOTION TRACKING IN MRI BY HARMONIC STATE MODEL: CASE OF LEFT HEART

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ABSTRAK

We discuss about development of a new method of tracking closed contour which is based on a Harmonic State Model (HSM), in order to carry out the tracking of Left Ventricle (LV) during all the cardiac cycle. The Lionel's method provides us the trajectories of the LV contour from the tracking of motion during the cardiac cycle, and information necessary to the analysis of the cardiac motion. Using the HSM model allows a robust and correct modeling of closed contour. The application in simulation of Lionel's method gives satisfactory results. On the real data extracted from MRI sequences, the calculated trajectories, points of the LV contour throughout the cardiac cycle, allow to have a clearly visible difference between a healthy heart and a pathological heart.

Key Words: Harmonic State Model,Lionel's Method, Cardiac Cycle.

INTRODUCTION

The cardiovascular diseases, who are important cause of mortality in the whole world, are caused mainly by a disturbance of the contractile function of the heart which is carried out by the myocardium, and in particular the Left Ventricle (LV). The tracking of the LV motion allows the following of a great number of cardiovascular diseases.

The direct interpretation is very difficult to do because of the weak resolution and the strong presence of noises on the MRI images. The technique of space-time modeling is an

excellent alternative which gives many parameters for the analysis. Its use respects three stages: segmentation of the contour of the LV starting from the cardiac images and modeling (2D/3D) of the LV form, temporal tracking of the LV motion and finally the analysis of the parameters calculated at the time of the two preceding stages for the emission of the diagnosis. In the Lionel's work, they only focus in the second stage that is the temporal tracking of the LV motion. The tracking of the LV motion is a key phase in the process of analysis of cardiac sequences.

Currently, the tracking is still lack of precision or its cost of high calculation when the result is satisfactory. The objective are to present a new tracking method which wants to be at the same time specified and adapted to the tracking of periodic forms like the left ventricle and to differentiate a healthy heart and a pathological heart.

METHOD

Harmonic State Model

Method of harmonic state model can find the points on the contour. This model was useful for temporal modeling of the left ventricle motion (periodic motion). The left ventricle is modeled by a closed contour. This one can be described by a continuous and periodic function (eq.01) obtained by development of contour around its center of gravity ρ (θ). l is the number of sample related to θ, N is the number of samples and $\Delta\theta = 2\frac{\pi}{N}$ the step of this sampling in angle θ. The function ρ (θ) presents a periodicity related to θ (θ takes value from 0 to 2π). If one considers the decomposition in Fourier series, this function can be written in form (eq. 02).

The term $\overline{\rho}$ is the average value, ω the pulsation and n the number of harmonics. The coefficients a_i and θ_i respectively represent the amplitudes and the phases of the various harmonics.

This paper showed that such an evolution can be modeled by a harmonic model state of order n. This model was exploited in a temporal dimension to model the movement of the left ventricle (periodic movement). The periodicity of the form allows a transposition of the model in space dimension, introducing thus constraints of form and smoothing via he harmonic decomposition. This model is dynamic, linear model and makes it possible to associate a harmonic decomposition in Fourier series a linear dynamic model.[1]

Using Kalman filter in the HSM model offers the advantage of providing a robust estimate to the noises as well as parameters of the state vector of the model. The vector of associated state is then composed of $2n+1$ elements (eq.03).

$\rho^{(i)}(\theta)$ represents the derivative of the order j compared to θ. The equation of state of the dynamic model is in the form (eq.04).

The matrix is a matrix of calculated transition F^{θ} according to the step from sampling $\Delta\theta$, and $\zeta p(\theta)$ is a Gaussian noise with null average.

The state vector is a 2D local descriptor of left ventricle contour wall to the point control level. For a position θ, left ventricle contour ca restored by a series of recursive multipications of state vector $R(\theta)$ and matrix of transition $F\theta$.

This model makes it possible to generate as many points as one wish on contour and to associate a state vector to them which characterize them.

Lionel's tracking method

The objective of this method is to be able to track the points of the Left Ventricle contour throughout the cardiac cycle, and to be able to rebuild their trajectory.[2]

$$\rho_l = \rho\,[(\theta_0 + l\,\Delta\theta)] \text{ with } l = l, ..., N \quad \text{... eq. 01}$$

$$\rho(\theta) = \overline{\rho} + a_1 \sin(\omega\theta + \theta_1) + ... + a_n \sin(n\omega\theta + \theta_n) \quad \text{... eq. 02}$$

$$R(\theta) = \overline{\rho}, \rho(\theta), ..., \rho^{(2n-1)}(\theta))^T \quad \text{... eq. 03}$$

$$R(\theta) + \Delta\theta) = F^{\theta} R(\theta) + \zeta p(\theta) \quad \text{... eq. 04}$$

$$D_{Eucli}(X,Y) = \sqrt{\sum_{i=o}^{n-1} (x_i - y_j)^2}$$

with X,Y vector of size n ... eq. 05

$$Corr(X.Y) = \frac{Cov(X,Y)}{Cov(X,Y) * Cov(X,Y)}$$

with $Cov(X,Y) = E(X,Y) - E(X) * E(Y)$
where $E(X)$ is the average
of vector X ... eq. 06

In this tracking method, use the Harmonic State Model as a base to modeling surface 2D of the left ventricle. The Harmonic State Model offers a good modeling of a closed contour (a periodic evolution).

This method for track the points on each contour. For example, on each contour there are 20 contours, and each point called $p_1, p_2, p_3, ..., p_n$ the first point on the first contour will track the first point on the second contour and to be able to rebuild their trajectory.

As the state vector of the HSM is a local descriptor, the tracking of the motion is carried out on the level of each point by search for similar state vectors. Being given a point of control p of the left ventricle contour, C_t at the moment t, with state vector Rp_t , determine which point of C_{t+1}contour at the moment $t+1$, after movement , has a state vector very close to Rp_t.

In order to carry out this, was called upon several methods of measurement of distance between vectors. After a study of existing measurements and multiple simulations, retain two measurements for their excellent results: the Euclidean distance (eq.05) and the measurement of correlation (eq.06).

The angular opening of the window of research, which defines its size, influences the results of the method. Simulations tests enabled us to give him the value of 20°. Measure proximity: To select a point q_j in research window as being closest to p_i , the value of measurement between Rp_i and Rp_j must in the case of:

a. Euclidian distance, to minimize the distance enters the two vectors

b. Measurement of correlation, to maximize probability, is thus to have measurement nearest to 1 in absolute value.

RESULT AND ANALYSIS

This work goes from the segmentation of the heart in sequences of images to its analysis, while passing by the modeling of the form and the tracking of the heart motion (fig. 1). According to the type of approximation, this research use non-rigid motion of the left ventricle.

The actual data have been made on the basis of 3D + time cine-MRI clinically validated from the assistance of the institute Gaspard-Monge and laboratory A2SI. This database contains the contours extracted from left ventricle. The images are those of 18 patients with 25 or 22 images 3D per patient (fig. 2).

After get the contour from each period of cardiac cycle, determine the point in the contour C_t and then compare with the point in the next contour C_{t+1} based on a window that was created. Figure 3 present the tracking process from one contour to another contour by calculating the distance between the points in each contour.

This figure below, show the result of tracking method. In these trajectories, the shape is consistent with the cardiac movement. The trajectories of the outer contour are more crushed than the internal contour, and this corresponds to the fact that the outer wall of the left ventricle is more static than the inner wall. The collapse of the trajectories of the inferior part of the inner wall suggests a dysfunction of this part (fig. 4.).

In the figure 5, we can see the result of trajectories of 3 different patients which each patient has different symptom. The first trajectories present the sign of the healthy heart. The trajectories of the outer contour more crush and the movement is static. While the trajectories of the inner contour more shape. The speed variations in this case are regular and not sharp on all regions of left ventricle. The movement is synchronous in all regions.

The second trajectories provide the pathologic heart, in this case call dyskinetic. The trajectories movement was very crowded in both of outer and inner contour. The speed variations change very extreme from one point contour to the other. For the last, the trajectories have a small size. These trajectories indicate a limited movement of the inner and outer contour. From this movement can be provided that the speed of heart was limited and weak. In this case, the trajectories provide the hypokinetic cardiac pathology.

CONCLUSION

An important point in tracking the movement of the LV is to make a judicious compromise between the quality of tracking and taking into account the specificities of the latter, as it contains information concerning its pump function. Based on the model of the HSM, Lionel and friends have carried out a 2D contour modeling of Left Ventricle at each time cycle. This approach exploits the spatial modeling of the model, which had not yet been made, and its resistance to noise. This model allows finding the characteristic points of the contour. In addition to the trajectories, they gain settings helping with the issue of diagnosis. The experimental results are lead on a base of real images provided by clinic exams. The analysis of various parameters generated from these images can provide guidance on the clinical status of patients.

This new method makes it possible to make easily and in an instantaneous way the distinction between a pathological heart and a healthy heart by the rebuilding of the trajectories.

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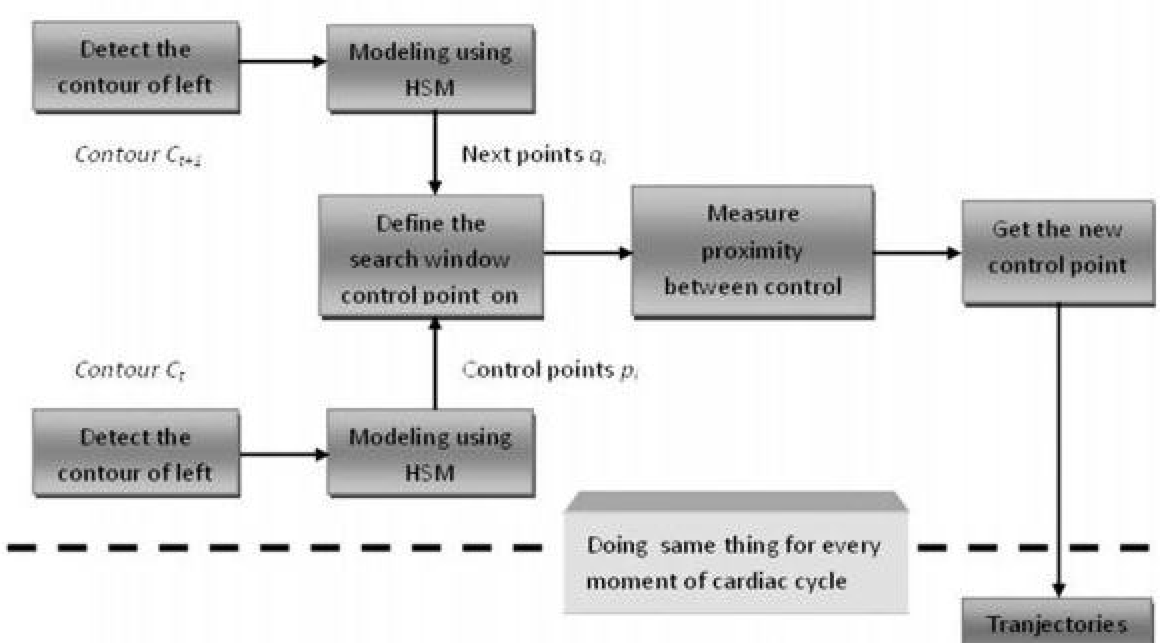


Figure 1. Tracking method

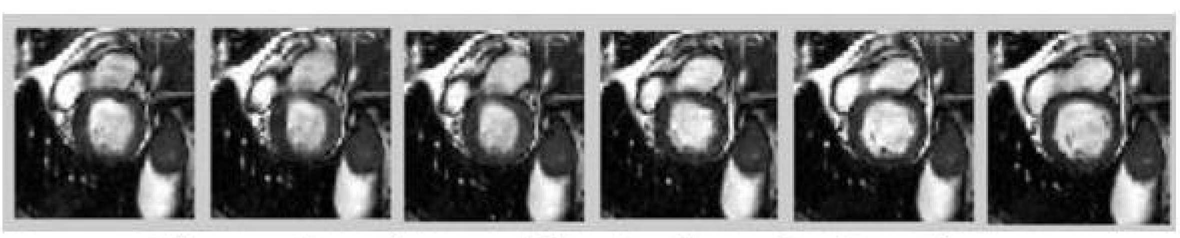


Figure 2. Some images of the 3D volumes for the patient 4

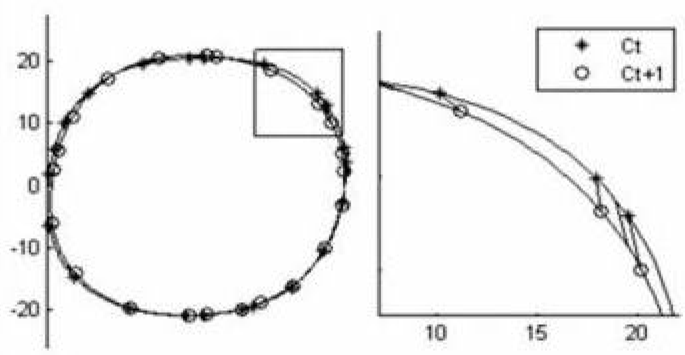


Figure 3. Position and correspondence between the interest points of C_t contour and those of C_{t+1} contour

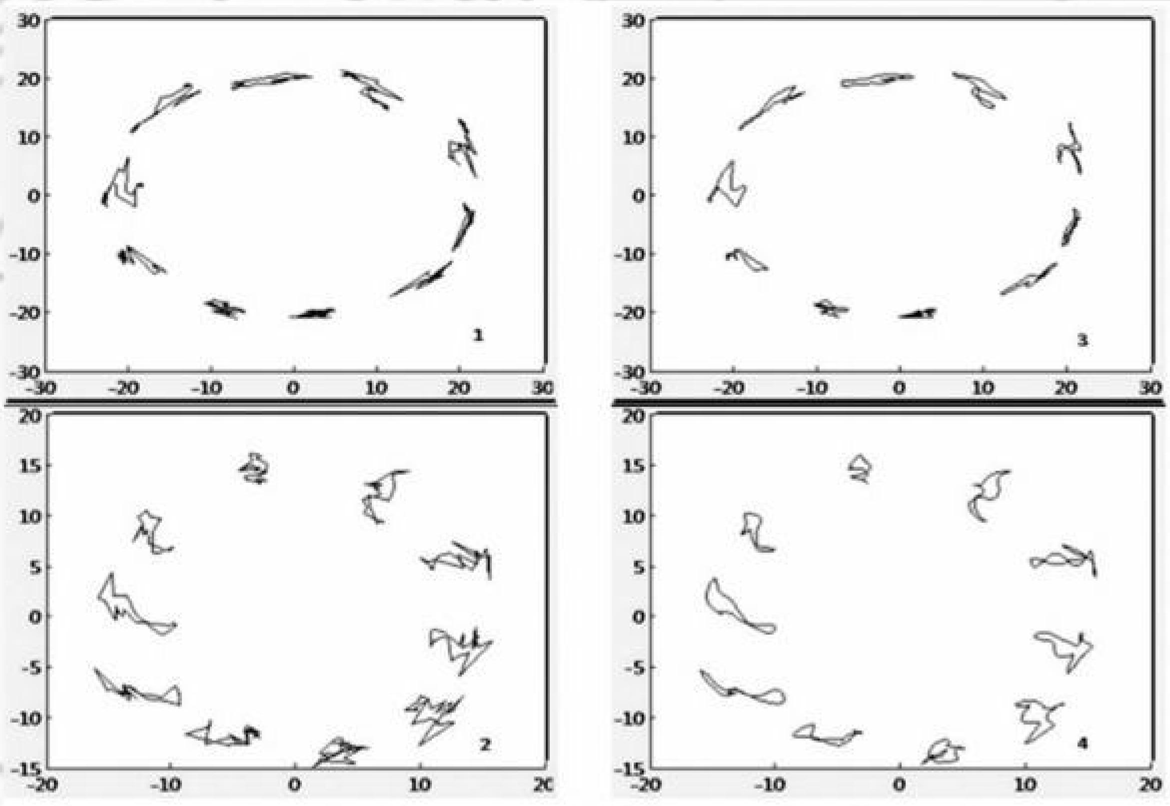
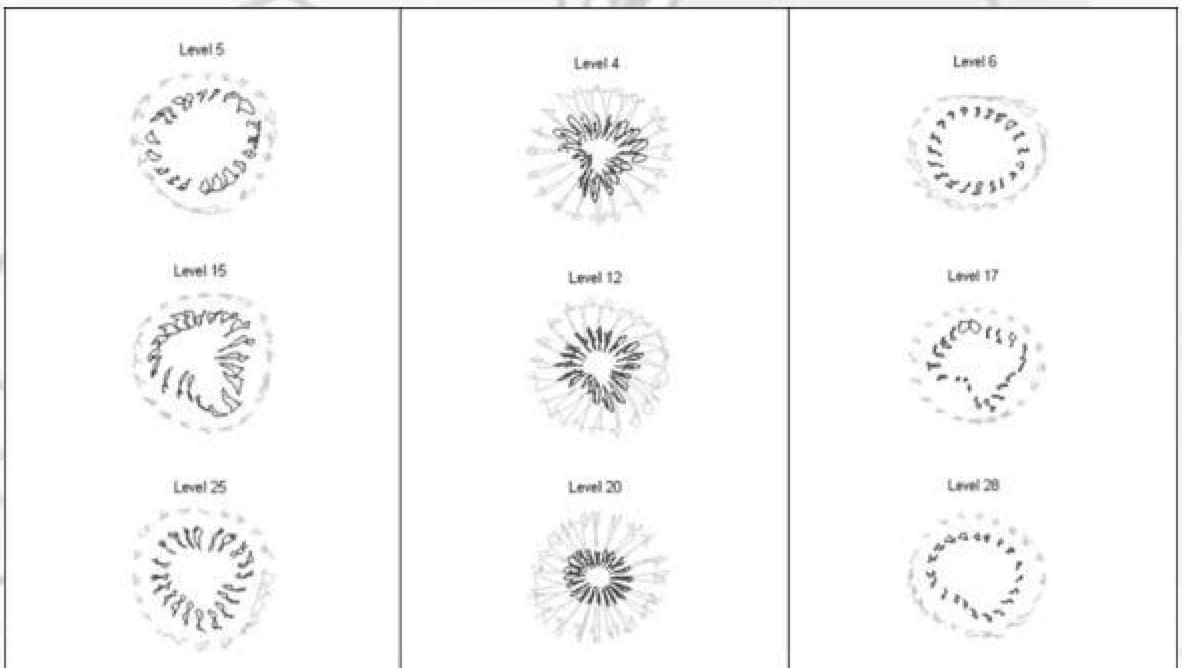


Figure 4. Trajectories of control points: (1) epicardium and (2) endocardium; modeled trajectories modeled by HSM model: (1) => (3) and (2) => (4)



(a) Patient with a healthy heart	(b) Patient with a dyskinetic heart	(c) Patient with a hypokinetic heart

Figure 5. The trajectories graph of 3 different patients