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# Computing rotation centers of the heart from tagged MRI

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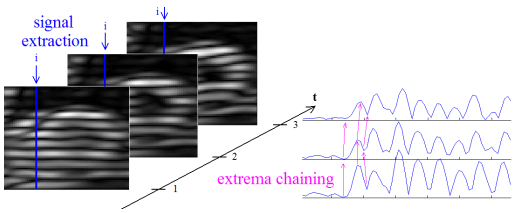


*Figure 1.* Basic principle of ETC.

## 1. Introduction

In order to understand the mechanism of the heart, clinicians and researchers analyze global and local deformations of the cardiac muscle and strive to measure the parameters of its movement. In this context, our purpose is to estimate the twisting part of the deformation of the cardiac muscle, which is a major parameter. Our approach is based on the following two main steps: first, the analysis of the twisting requires the use of a non-conventional cardiac imaging technique: tagged MRI is the chosen technique. Second, our work presents a novel heart's twisting modeling, a dilatation-rotation model which estimates the deformation of closed curves located in the left ventricular on short axes views. Section 2 recalls the physic principle of tagged MRI combined to a processing method called ETC. Section 3 presents the movement's modeling and its parameters estimation. Section 4 shows the corresponding main results.

## 2. Tagged MRI and ETC method

Tagged magnetic resonance imaging (MRI) techniques enable the visualization of inner-wall motion of the heart: it consists of adding a regular pattern at the beginning of a normal cine-MRI sequence. The most usual pattern (SPAMM [1], CSPAMM [2]) is a set of 2 orthogonally tagged sequences with a sinusoidal-like profile, yielding alternating white and black stripes.

A fast and automatic analysis method called ETC [3] was developed. ETC proposes an original description of tags as local minima of 1D signals. These signals are related to the lines or the columns of the images. This leads to a new formulation of the tag tracking problem as an Extrema Temporal Chaining (ETC, see Figure 1). We validated and compared its results to another classical method called HARP (HARmonic Phase images) [4].

## 3. Contraction-rotation modeling

Measuring the twisting angle and the contraction factor requires to choose any short axis plane, where the inner-wall rotation is the most visible. Usually, the gravity center is assumed to be the rotation center and is not linked to the movement. Such assumption being not valid, it will not be made in this work: the rotation center is supposed unknown.

**Dilatation-rotation equation.** Thus we directly model the curve's deformations as an infinitesimal contraction-rotation movement. We assume two hypothesis: the curve's contraction is a dilatation, and both transformations have the same center $\vec{C}_0(t)$. Let us consider the deformation between times $t$ and $t+dt$. Let $\vec{R}_\theta = \theta\vec{z}$ be the instant rotation vector, $\vec{z}$ being a unitary vector perpendicular to the imaging plane. Let $\lambda(t)$ be the dilatation factor and $\vec{M}(t)$ be the position vector of any point of the considered curve at time $t$. We obtain the final movement equation by combining (i.e composing) the dilatation to the rotation:

$$\begin{aligned}\vec{M}(t+dt) = \\ = \lambda(t).[\vec{M}(t) - \vec{C}_0(t) + (\vec{M}(t) - \vec{C}_0(t)) \wedge \vec{R}_\theta(t)] \\ +\vec{C}_0(t)\end{aligned} \quad (1)$$

**Dilatation factor derivation.** This Equation 1 contains 4 parameters: $\lambda$, $\theta$, and the two coordinates of the rotation center $\vec{C}_0(x_0, y_0)$. Let $S(t)$ denote the inner area of the curve $C(t)$ at time $t$. We can directly derive the dilatation ratio $\lambda(t)$ from the curve's deformations thanks to the formula :

$$\lambda(t) = \sqrt{\frac{S(t+dt)}{S(t)}} \quad (2)$$

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**Rotation estimation.** Let us define $\mu = \frac{1}{\lambda(t)}$, $\vec{M}(t)\begin{pmatrix}x_1\\y_1\end{pmatrix}$ and $\vec{M}(t+1)\begin{pmatrix}x_2\\y_2\end{pmatrix}$. Then Equation 1 entails two scalar equations which may be rewritten :

$$\begin{cases} (1-\mu)x_0 + y_0\theta = x_1 - \mu x_2 + y_1\theta \\ (1-\mu)y_0 - x_0\theta = y_1 - \mu y_2 - x_1\theta \end{cases} \quad (3)$$

This highlights the left hand sides of both equations, which don't depend on the considered point. Then we may remove $x_0$ and $y_0$ by subtracting those equations for different points number $j$ and $k$ of the curve $C(t)$, and perform a mean square minimization:

$$\theta = -\frac{\sum(\alpha_{jk}\beta_{jk} + \gamma_{jk}\delta_{jk})}{\sum(\beta_{jk}^2 + \delta_{jk}^2)} \quad (4)$$

where $\alpha_{jk} = x_1^j - \mu x_2^j - (x_1^k - \mu x_2^k)$, $\beta_{jk} = y_1^j - y_1^k$, $\gamma_{jk} = y_1^j - \mu y_2^j - (y_1^k - \mu y_2^k)$ and $\delta_{jk} = x_1^j - x_1^k$.

**Center estimation.** Considering we know $\theta$ from Equation 4, we estimate $(x_0, y_0)$ with the 2 parameter formulation of the mean square estimation.

## 4. Results

We draw 2 curves on the endocardium (red) and on the epicardium (blue). Then we perform the estimation on both curves and on all pixels contained between them. This is successfully done for 40 rats' and 40 patients' sequences.

**Contraction and twisting.** We plot the cumulated values of the twisting and of the contraction $(\sum_t(\theta(t)), \prod_t(\lambda(t)))$. Figure 2 shows a representative example of resulting signals, highlighting the twisting inversion phenomenon. Those data come from 2 rats, one healthy (solid signals) and one presenting an infarct near the apex (dashed signals). Both twisting and dilatation show the loss of the beating performance in this area (levels 1 and 2).

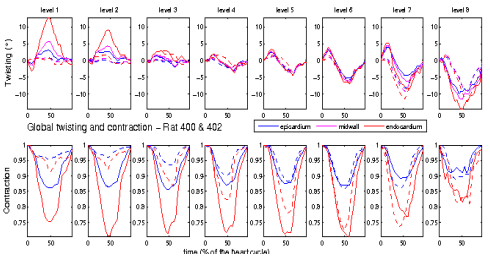


*Figure 2.* Twisting and dilatation factor on short axis planes, from the apex (left) to the base (right).

**Localization of the centers.** Concerning the localization of the centers, the results are very inhomogeneous. Therefore we only consider the centers corresponding to $\theta \geq 1$. We compute the standard deviation of their positions related to the epicardium's diameter. The mean values are 30% for the endocardium, 38% for the myocardium and 40% for the epicardium. The corresponding meaningful centers are almost always inside the bloody cavity (80%, see Figure 3), and often closer to the septum. This is in agreement with the weak deformations occurring in this area.

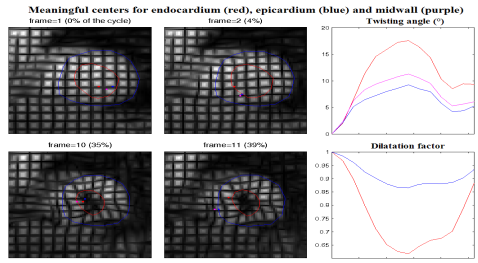


*Figure 3.* Selected centers of a Patient's sequence, with the corresponding twisting and dilatation.

## 5. Conclusion

We performed an original movement estimation on a curve which gives information about the twisting, the contraction and the center's location. The center's positions are intuitively well located for big angle values : in the bloody cavity, near the septum. This proves the relevance of the performed modeling. Moreover, we obtain an objective quantification of the contraction factor and of the rotation angle at different depths inside the myocardium. The results are smooth and give a good description of the curve's global movement.

## References

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