A model-based time-reversal of left ventricular motion improves cardiac motion analysis using tagged MRI

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Introduction

Myocardial motion is an important observable for the assessment of heart condition. Accurate estimates of ventricular (LV) wall motion are required for quantifying myocardial deformation and assessing local tissue function and viability. Harmonic Phase (HARP) analysis was developed for measuring the regional LV motion using tagged magnetic resonance imaging (tMRI) data [1]. With current computer-aided postprocessing tools including HARP analysis, large motions experienced by myocardial tissue are, however, often intractable to measure. This paper addresses this issue and provides a solution to make such measurements possible.

Materials and Methods

To improve the estimation performance of large cardiac motions while analyzing tMRI data sets, we propose a two-step solution [2]. The first step involves constructing a model (**T**) to describe the average systolic motion of the LV wall within a subject group. The second step involves reversing this model in time ($\mathbf{T}^{-1}$) and applying the inversion as a spatial transformation to digitally relax the contracted LV wall in the experimental data from each subject to the beginning of systole.

The mathematical basis of the model is an extension of the approaches employed in physical sciences - typically to simplify otherwise complex, intractable problems representing a physical phenomena. For example, quantum wells are used in solid state physics to understand the distribution of electron density in spatially confined potentials. Similarly, gravitational wells are used in astrophysics to represent forces of large masses acting on smaller bodies to shape their orbits. Hence, analogous to these cases, we approximate the LV systolic motion at the mid-ventricle with a well that is shaped by a two-dimensional Gaussian profile with a single parameter α.

Cardiac MRI data from the mid-ventricle level were collected from four male Sprague-Dawley rats. The rats were anesthetized using 1.5% isofluorane in a mixture of air and oxygen (60% and 40% respectively) and scanned using a 9.4 T scanner and 60 mm radio frequency volume coil. ECG gated gradient echo based tagged images were captured from the short-axis view of the heart. The cardiac cycle was temporally resolved into ten equally incremented phases. The first five were the systolic frames. The following settings were used for the image acquisition: repetition time = 25 ms, echo time = 2.44 ms, number of averages = 1, field of view = 60 x 60 mm, image matrix = 256 x 256, slice thickness = 2.0 mm. The square grid tags had dimensions of width = 0.3 mm and separation = 0.8 mm. Algorithms were implemented for preprocessing the tMRI data, optimizing the model parameters and performing the HARP analysis [2].

Results and Discussion

The model parameter determined for each frame in systole is given in Table 1. The time-reversal operation derived from the LV model accounted for the bulk portion of the myocardial motion, which was the average motion experienced within the overall subject population. In analyzing the individual tMRI data sets, removing this average with the time-reversal operation left small magnitude residual motion unique to the case (Fig. 1). This remaining residual portion of the motion was estimated robustly using the HARP analysis (Fig. 2).

Conclusions

Utilizing a combination of the forward LV model and its time reversal improves the estimation performance in cardiac motion analysis. Preliminary data indicates that the model parameters are sensitive to detect cardiac dysfunction in diabetic cardiomyopath.

References

[1] Osman NF, et al. *Magn Reson Med* 1999, **42**(6):1048-1060.

[2] Alrefae, T. et al. Submitted. 2007.

Table 1. The values (mean ± std) for the parameter α estimated using the tMRI data acquired from the control rats (n=4). Because the MR sequence applies tagging gradients in the image frame i=1(end diastole), the first noticeable deformation in tag lines occurs in frame i=2.

Frame	α (pixels)
2	12.0 ± 0.8
3	16.0 ± 0.6
4	19.0 ± 0.4
5	20.0 ± 0.8

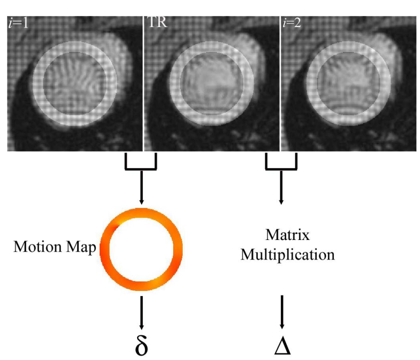

Figure 2. Utilizing time-reversal, the bulk motion **Δ** between I_2 and the time-reversed image TR is computed. The residual motion **δ** between TR and I_1 is estimated by a phase-wrap free HARP analysis.

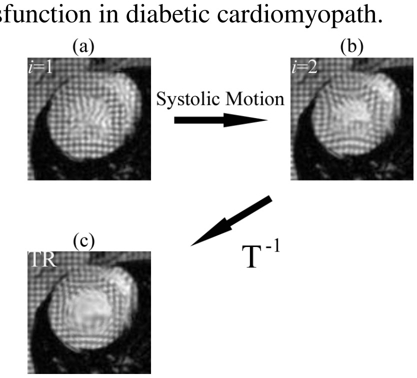

Figure 1. Systolic motion changes image I1 (a) to I2 (b) causing large wall motion. Applying time-reversal to I2 yields a time reversed image (c) with the LV wall tissues almost restored to its initial positions in I1.