A New HARP-based Method for Fast Tracking of 3D Cardiac Motion

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Synopsis We present a fast and semiautomatic method for tracking 3D cardiac motion from short- and long-axis tagged MRI images. The technique is based on the harmonic phase (HARP) method and extends it to track 3D motion. The phase time-invariance property of material points is used for motion tracking. The total time required for tracking 3D cardiac motion is ~10 minutes. Further analysis of Lagrangian strain and twist angle demonstrates that during systole, the lateral left ventricle wall shows a greater strain than the septum and the short-axis slices show a gradually changing twist pattern.

Introduction Tagged MRI enables quantitative evaluation of regional myocardial function, which is valuable for diagnosis and treatment of heart diseases. However, existing 3D cardiac motion analysis techniques require cumbersome and semiautomatic segmentation of endocardium and epicardium and tracking of tag locations, which is very time consuming. HARP¹ has been proposed as a fast analysis technique that exploits the Fourier spectrum of tagged MRI images, which overcomes the above drawbacks of other existing methods. However, HARP was originally developed to measure only 2D cardiac motion. This work extends the HARP method to track 3D motion of the heart from short-axis (SA) and long-axis (LA) images.

Methods Two SA sets (6 slices with horizontal and vertical tag lines) and one LA set (6 slices) of tagged images from a normal volunteer are used in this study. The images are obtained on a GE 1.5T Signa scanner (GE Medical Systems, Milwaukee). Each image series is acquired during systole (9 timeframes with time separation of 33ms).

A 3D mesh is built inside the left ventricle (LV) wall at the first timeframe. The mesh is a collection of material points with internal mechanical properties which determine the smoothness and elasticity of the mesh. The concept is that the harmonic phase of each material point on the mesh is time-invariant, which is the same principle used in conventional 2D HARP tracking. The harmonic phase values of the material points on the mesh are initialized at the first timeframe. Since the tagged images are sparse, the phase time-invariance condition is checked only at the points where the deformed mesh intersects with the image planes. If this condition is not satisfied, the phase differences between initialized phase and observed phase of all the intersection points will generate a displacement field using 2D HARP to deform the mesh. This deformation is repeated at each timeframe until the phase time-invariance condition is satisfied.

Results The initial 3D mesh is manually created only at the first timeframe (end-diastole) inside the myocardium — this is the only step that requires human interaction. The subsequent steps of mesh point tracking are totally automatic. The deformation of the mesh at each timeframe converged to satisfy the phase time-invariance condition in less than 10 iterations per timeframe. The total time for building and tracking the mesh is about 8 minutes.

The result of this tracking is shown in Fig. 1, in which an early tilt at the lateral side towards the apex and a different twist pattern of SA slices can be examined. The Lagrangian circumferential (LC) strain was computed from the deformed mesh. Fig 2 shows that the average LC strain in the lateral wall is greater than that of the septal wall. Fig 3 shows that at early systole, all slices rotate counterclockwise (seen from the apex). Then basal slices reverse their rotation direction and plateau at late systole, whereas more apical slices maintain the trend of rotation throughout systole. [²]

Conclusion and Discussion This HARP-based method is a fast and semiautomatic analysis technique to track 3D cardiac motion. The phase time-invariance property of material points provides an important condition to guarantee that the deformation of the mesh is correct. This algorithm is currently implemented in Matlab (Mathworks Inc.), but we expect it to be much faster if implemented in C.


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