In-Vivo Validation of 4D B-Spline-based Motion Tracking Algorithm for Cardiac Tagged MRI

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Introduction
In cardiac MRI, tags move with the contracting heart, and their distortion in subsequent images provides useful qualitative and quantitative information about functional properties of underlying myocardium [1]. We have previously reported a method to derive the heart motion from one dimensional tag displacement information [2]. In this method, a final four-dimensional tensor product of cubic B-splines describes warping of space as the heart contracts. This method allows us to represent the motion of the heart in a compact way and gives a natural solution which is smooth both in space and time. It does not rely on specific coordinate system and can be used for any structure. The purpose of this study is to determine the accuracy of this motion tracking algorithm in vivo.

Figure 1. Sample of short axis tagged cardiac MRI images. Top row: Set 1, tagging in diagonal directions. Bottom row: Set 2, tagging of the same slice in horizontal and vertical directions. Left column images are at first time frame, right column images are at last time frame. Imaging parameters: TR = 6.4-6.6 ms, TE = 1.7 ms, flip angle = 10, 256/192 matrix, FOV 32 cm, slice thickness 8 mm, tag spacing 7.5 mm.

Methods
In a normal volunteer, cardiac images were acquired using a segmented k-space breath-hold cine acquisition on a 1.5T scanner; both short and long axis images were taken throughout the cardiac cycle (11 phases). Two different tagging sets were acquired for the short axis image planes (Figure 1) and separate long axis images were acquired for each set.

Tag points were detected on all images of a given set and an initial 2D tensor B-spline inverse field was computed for each short axis image plane. With the incorporation of the through plane motion information from long axis images, for each tag point a matching point at the tagging time was found. The forward motion field was then computed which maps points at the tagging time back to their deformed locations as the heart contracts.

The two tagging sets (Fig. 1) produced two distinct parametric inverse motion fields for each imaging plane. These gave 2 independent sets of matching points between later time frames and the tagging time resulting in two separate 4D parametric forward motion fields.

Two metrics were used to evaluate the precision of the motion field. The first was the residual error which is the 3D distance between the original tag point and the position to which that tag point is mapped following the inverse and forward transformations. The validation error was the same distance between the original and forward transformed matching point but the forward field used parameters derived from the other tagging data set (Fig. 1).

Results
The optimal B-spline control point density for the inverse mapping was found to be 10x10. Using this inverse transformation, the forward motion field was computed for progressively higher control point densities (4x4x4, 6x6x6, 8x8x8, 10x10x10 in space and 8 in time, volume of interest was 120 x 150 x 80 mm). The respective residual errors were 1.39±.7, 0.77±.5, 0.50±.4, 0.38±.4 mm and validation errors were 1.46±.7, 1.20±.8, 1.21±1.0, 1.27±1.1 mm.

Discussion
For a given set the motion field describes the motion at subpixel accuracy. Although the residual error decreases with the increased control point density, the validation errors reach an asymptote. From the component analysis of the errors we conclude that through plane error is the most significant portion of the total tracking error.

The time complexity of field fitting is proportional to the CP number, but increased computation does not necessarily result in a better description of the cardiac motion. As the CP density increases, the accuracy of the motion field remains constant (and even slightly deteriorates), which might not be apparent if the field fit is guided only by residual error.

The low errors show that our method is successful in capturing the underlying motion of the heart. Optimum B-spline control point density for normal cardiac motion is 10x10 for inverse and 8x8x8x8 for the forward field.

References

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