Image-Based Tracking of Heart Valves for Improved Motion Compensation

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Introduction

Several methods over the last decade [1,2] have shown the efficacy of phase-contrast MR sequence for quantitative flow measurement in aortic and mitral valves. These methods usually select a single slice containing the valve of interest, that is imaged throughout the cardiac cycle. The significant motion of the valve planes (max motion ~ 10-15 mm) through the cardiac cycle (see Figure 1) moves it in and out of the imaging slice thereby sometimes providing inaccurate measurements and poor visualization. Recently, [3,4] proposed the use of tagging to estimate the valve plane through the cardiac cycle offline during a pre-scan, and then acquiring the data by adaptively moving the slice at different time points in the cardiac cycle with the motion estimated during the pre-scan. These methods showed improvements in flow measurements but suffered from the disadvantage that tags fade with time, making the estimation difficult in later parts of the cardiac cycle.

Proposed Approach: The basic idea behind our proposed approach is to track the valve plane throughout the cardiac cycle so that while imaging, the slice can be adaptively positioned to be in the valve plane. Unlike earlier approaches [3,4] using tagging, we propose an image-based tracking algorithm to estimate the valve plane. Since the tagging approaches use a different breathhold for tracking compared to data acquisition, there could be an unknown offset in valve plane positioning due to either hysteresis effects or shift between different breathholds. To overcome this problem, we propose real-time tracking in one or two breathholds before switching to the data acqusition to account for this offset. In this work, we present the feasibility of tracking mitral and aortic valves in both high-resolution segmented cine images and low-resolution real-time images in 4-chamber and coronal views respectively.

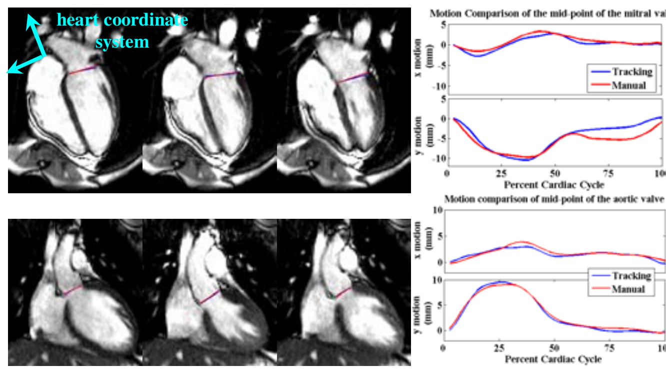

Figure 1: Comparison of valve tracking (blue) against manual selection (red) for both mitral (top row) and aortic valves (bottom row).

Methods

MR Acquisition: We acquired high resolution cine images in 4-chamber, coronal and short axis views in 5 volunteers (4 males, 1 female, age range 22 to 41) with the following parameters: TR/TE/FL = 1.9-2.08/ 1.45-1.54/ 69-80, GRAPPA acceleration = 2, in plane reconstructed resolution = 1.6 - 1.92mm, slice thickness = 6mm, Acquisition matrix size = 120 x 192 –156 x 192 pixels, temporal resolution = 21-33msec, on a 1.5T scanner (Espree, Siemens). We also acquired real-time breath-hold SSFP images with the following parameters: TR/TE/FL = 2.18-2.28/1.09-1.14/49-56, GRAPPA acceleration = 2, in plane reconstructed resolution = 2.76 - 2.89mm, slice thickness = 6 - 8mm, Acquisition matrix size = 50 x 128 – 68 x 128 pixels, Interpolated matrix size = 88 x 128 – 112 x 128 pixels, with the subjects holding their breath at end-expiration.

Tracking: Due to the large complex motion of the mitral and aortic valves, they are not visible throughout the cardiac cycle in 4-chamber and coronal views respectively, therefore their motion is estimated by tracking the region around the end points of the valve. The valve is then localized by the line segment joining the two end-points. The appearance of the region surrounding the valve end points also changes significantly through the cardiac cycle, thereby requiring multiple templates (reference regions) to track the valves accurately. The basic idea behind the tracking approach is that the appearance of the target region is a rigid body transformation of an affine combination of the templates. A sum-of-square-differences (SSD) optimization simultaneously computes both the location and affine mixture in each image in real-time. Further details of the tracking algorithm can be found in [5]. Both the aortic and mitral valves were tracked in high resolution cine images and low-resolution real-time images.

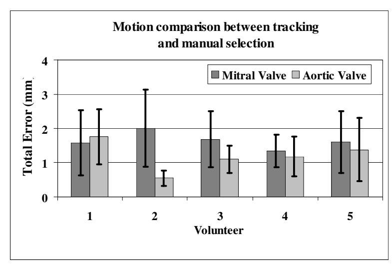

Figure 2: Valve motion comparison across all volunteers.

Process Flow: Currently, the algorithm for tracking in high-resolution cine images is semi-automatic requiring user input for the selection of templates. In order to speed-up the template selection, the user is guided through 4 frames in the first half of the cardiac cycle where templates or reference locations of valve end-points are selected. These 4 frames were picked at approximately 0, 15, 37 and 50 percent of the cardiac cycle length for high resolution cine images. For real-time images, usually 2-3 templates were chosen at end-systole, mid-diastole and end-diastolic time points in a cardiac cycle.

Validation: We validated the tracking against manual selection in high resolution cine images. The end-points of both mitral and aortic valves were selected manually throughout the cardiac cycle in 4-chambers and coronal views respectively. Note that as the valve itself is not visible throughout the cardiac cycle, manual selection is difficult, but is the only feasible method for comparison. Both the tracked and manually selected motion data was filtered with Savitzky-Golay and Gaussian filters to remove noise and jitter. The motion data from all volunteers in the 4-chamber view was transformed into a consistent coordinate system (see Figure 1), that was computed using the 4-chamber and short axis slice orientations. The error between the tracked and manually selected mid-point of the valves was computed. The mean and standard deviation of the total error throughout the cardiac cycle was computed for all volunteers in both views.

Results

The comparison of the tracking algorithm against manual selection in high resolution cine images is shown in Figures 1 and 2. The tracking peformance for both mitral and aortic valves in a single volunteer is shown in Figure 1. Figure 2 shows the mean and standard deviation of the total error between the tracked and manually selected location of the valves in all 5 volunteers. The tracking of the mitral and aortic valve plane in real-time images for a volunteer are shown in Figure 3. The tracking accuracy in real-time images was assessed visually and were found to be in good agreement.

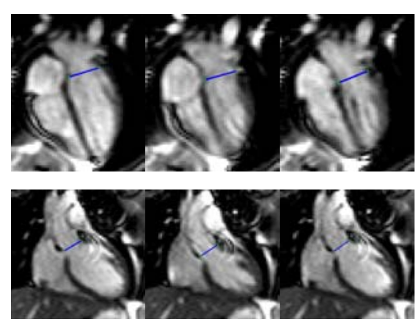

Figure 3: Tracking of mitral and aortic valves in real-time images.

Discussion

We have presented an algorithm for tracking the aortic and mitral valves in both real-time and high resolution MR images. Since the approach is applicable to both triggered segmented images and real time images, it has potential for application in MR guided valve repair and replacement procedures in addition to diagnostic use.

References

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