Fast Image Registration for Real-Time Cardiac MRI Guided Intervention

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Problem

Cardiac interventional procedures such as myocardial stem cell delivery and electrophysiological (EP) ablation require a high degree of accuracy and efficiency. Real-time (RT) MR guided interventions would be enhanced by acquiring a 4D (3D + cardiac phase) volume prior to the procedure and aligning it to the 2D RT images, so that the RT images can be visualized within the 3D context of the prior volume (PV), as shown in Fig. 1. By means of the prior volume further information could be integrated, such as a registered normal EP map with an ablation plan. Traditional registration algorithms may require 5 s or more processing time; however, RT MR images are often acquired at 10-15 frames / s, (FPS). We propose a registration algorithm optimized for high speed and RT MR, that provides 3-4 mm alignment accuracy at 16 FPS.

Methods

During RT scanning, ECG and scan-plane geometry data is streamed from the scanner to the visualization software. The ECG provides the cardiac phase to select a 3D volume from the 4D PV, and the latter is used to select a 2D image from the 3D volume, reducing the problem to a 2D-2D image registration. Our 2D registration algorithm employs speed-optimized mutual information (7 bins) to measure the similarity of the RT and PV images, and a simplex search technique to determine the 3 (angle, x, y) transformation parameters. Nearest neighbor interpolation was used to transform the image points for similarity measurement. The registration algorithm uses a uniformly sampled set of points from an automatically defined region of interest (ROI) in the image pairs to calculate the mutual information metric, sampling significantly fewer than the total number of ROI pixels, so that the registration processing time can be substantially reduced. Increasing the number of samples generally improves registration accuracy at the expense of increased execution time, so the sample number was investigated to balance these critical requirements. Furthermore, the registration parameters were initialized by the results of the previous frame of the imaging sequence. The default ROI is an 80 x 80 pixel region (100 x100 mm) at the centre of the image, since our clinical protocols routinely centre the myocardium during cardiac MR scanning. 4D PV images were acquired using balanced-SSFP cine (256 x 256 pixels, 32cm FOV, 6 mm slice thickness and 20 phases per cardiac cycle). Two balanced-SSFP RT pulse sequences were used with 128 x128 pixels up-sampled to 256 x 256, 32 cm FOV, and 6 mm slice thickness. Six subjects were scanned using a Cartesian acquisition at 3 FPS, and four subjects using a spiral acquisition at 15FPS. Furthermore, the subjects were asked to follow two respiratory protocols, with either normal or heavy breathing during RT scanning, to examine the algorithm robustness under different motion conditions.

Results

Registration accuracy was measured by comparing the high-speed registration alignment against a manual, landmark registration determined by a single human observer. Fig. 2 shows the variation in registration accuracy for four pixel sample quantities (250,500,1000,2000); alignment of heavy breathing image sequences shows a small but noticeable improvement with higher sample numbers. We therefore elected to use the largest number of samples that satisfied the processing time requirements of our pulse sequence. Execution with 1000 (6.1%) samples required 60 ms computation time to complete registration, thus registering image pairs at 16 FPS. The inter-observer consistency between four observers registering a subset of our data was 2.70±1.45mm, while our high-speed registration had mean misalignments of 2.97±1.81mm and 2.90±1.34mm, during normal breathing for Cartesian and spiral imaging respectively. Under the heavy breathing protocol, high-speed registration misalignments increased to 3.81±1.89mm and 3.28±2.49mm with Cartesian and spiral imaging, respectively.

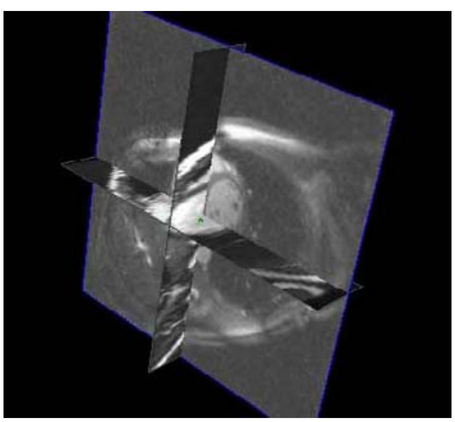

Fig. 1: Real-time MR image of the cardiac short-axis is shown in the large plane, and the 3D context of the prior volume is shown in the two orthogonal cut-planes.

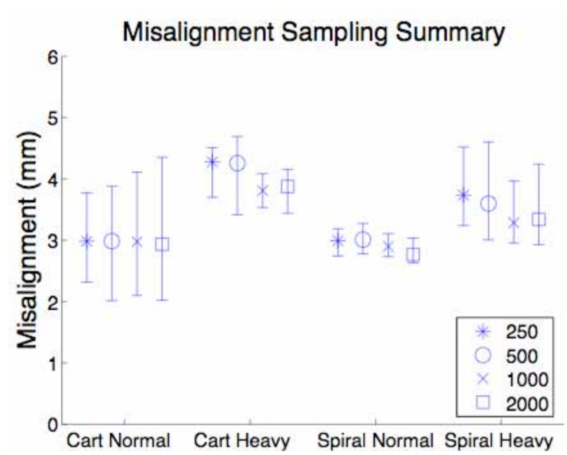

Fig. 2: Alignment accuracy of the high-speed registration algorithm using different number of pixel samples (symbols). The results are categorized by the pulse sequence and respiratory protocol pair.

Conclusion

A high-speed registration algorithm has been developed to correct for motion of the LV during real-time MRI scanning relative to a 4D prior volume that should improve intervention navigation and efficiency. The automated RT registration was able to correct for normal and exaggerated respiratory motion in healthy subjects with an accuracy comparable with retrospective, landmark registration by observers without time constraint.