Real-Time Registration by Contour Tracking for Interventional Guidance using Cardiac MRI

D. Chung[1], J. Satkunasingham[1], G. A. Wright[1], and P. Radau[1]

[1]Imaging Research, Sunnybrook Health Sciences Centre, Toronto, Ontario, Canada

Introduction

Real-time, 2-D magnetic resonance (RT-MRI) technology is being developed to guide cardiac interventional procedures that require considerable accuracy, such as regenerative and electrophysiological therapies. Interventional guidance would be enhanced by acquiring a 4-D (3-D + cardiac phase) volume prior to the procedure and aligning it to the 2-D RT images, so that the prior volume (PV) would be integrated with RT visualization. This technique provides 3-D spatial context with high resolution and SNR. A contour tracking system has been developed to maintain spatial alignment of the left ventricle (LV) between prior volume and real-time MR images. Having established intra-operative registration, the RT visualization could incorporate additional information by pre-procedural registration of the PV with a delivery plan and an atlas of normal anatomy and function. A contour tracking system for the LV myocardial walls was developed to compute the alignment transformations between the RT images and the 4-D PV, to provide rapid and robust RT myocardial spatial alignment. When compared to high-speed image intensity registration algorithms, the contour tracker offers the ability to accurately identify the location of the myocardial walls during RT scanning, as well as potentially improved robustness when RT-MRI contrast differs significantly from PV contrast.

Methods

Our contour tracker is the Condensation algorithm [1] optimized to track the LV endocardial and epicardial walls in RT images of the cardiac short-axis. We have developed a semi-automatic algorithm to segment the LV myocardial walls in the PV, providing the wall shape templates for tracking. Patient ECG and scan-plane geometry data is streamed from the MRI system to the visualization software during scanning to estimate the cardiac phase and slice in the 4-D PV that is the nearest match to the RT scan-plane. In principle, the tracker is able to estimate any parametric deformation of the shape template, although in this prototype, 2-D rigid (translation and rotation) transformations were applied to align cardiac short-axis images. The tracker generates random samples of the rigid transformation and measures the suitability of each sample by seeking edge features in the RT image that support the corresponding contour position. Edge feature information is used to weight each sample, and the weighted sample set is aggregated to provide a current state estimate, propagating the most recent state estimate to bias the sampling procedure for the next frame.

4-D PV images were acquired using balanced-SSFP cine, 256 x 256 pixels, 32 cm FOV, 6 mm slice thickness and 20 phases per cardiac cycle. Two balanced-SSFP RT pulse sequences were used with 128 x 128 pixels up-sampled to 256 x 256, 32 cm FOV, and 6 mm slice thickness. Six subjects were scanned using a Cartesian acquisition (FA=30°, TR=3.4 ms, TE=1.4 ms) at 3 FPS, and four subjects using a spiral acquisition (FA=45°, 644 readout points, 25 interleaves, 125 kHz bandwidth, TR=6.3 ms, TE=1.1 ms) at 15 FPS with a sliding window reconstruction. Furthermore, algorithm robustness was tested with two respiratory motion protocols, where subjects were asked to either breathe "normally" or "heavily" (deeply) during RT scanning.

Results

Registration accuracy was measured by comparing the contour tracker results against manual, landmark registration results determined by a single human observer. The inter-observer consistency of four distinct human observers for a subset of our test data was 2.70 ± 1.45 mm, a measure of the minimal meaningful misalignment. Contour tracking mean misalignments were 3.04 ± 1.37 mm and 2.77 ± 1.39 mm with the normal breathing protocol, for Cartesian and spiral imaging, respectively. Under the heavy breathing protocol, contour tracking misalignments increased to 4.10 ± 1.85 mm and 3.65 ± 2.16 mm with Cartesian and spiral imaging, respectively.

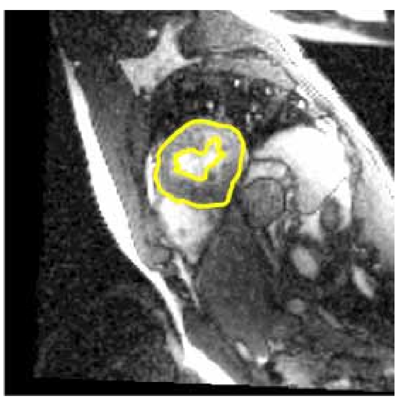

Fig. 1: Sample RT cardiac short-axis image, with myocardial wall overlays showing the tracked wall shapes.

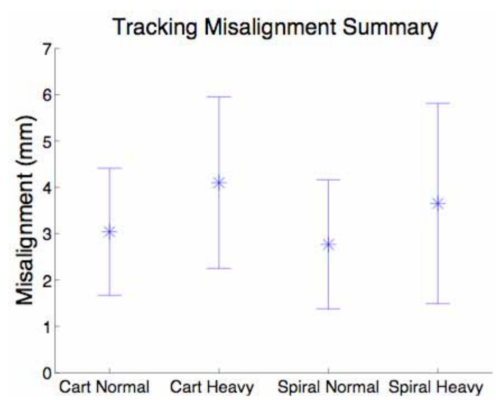

Fig. 2: Summary graph of mean RT-PV alignment accuracy categorized by pulse sequence and respiration protocol pairs. There are two pulse sequences (Cartesian and spiral) and two respiration protocols ("Normal" and "Heavy").

Conclusion

Quantitative evaluation indicated that our proposed real-time registration by tracking technique is able to align real-time MR images to a 4-D prior volume with similar accuracy to a human observer for a subject breathing normally, and only slightly poorer accuracy for a subject breathing heavily. The use of the myocardial walls to perform alignment may provide improved robustness when compared to image intensity based registration techniques, especially if the pulse sequence used during RT imaging were to produce images with substantially different contrast to the 4-D PV images. Future development will improve the workflow by completely automating the segmentation of the myocardium in the PV. The contour tracker provides a valuable step toward our next development, real-time characterization of changes in myocardial function during intervention, by monitoring changes in wall thickness. This could be critical during MR-guided interventions where ECG suffers from artifacts.

References

1. Isard, M., Blake, A.: Condensation - conditional density propagation for visual tracking. International Journal of Computer Vision Vol. 29 (1998).