Ventricular Tracking for Real-Time MR Scan-Plane Alignment during Guidance of Cardiac Interventions

Desmond Chung, Graham Wright, and Perry Radau

Sunnybrook and Women's Health Sciences Centre,
2075 Bayview Avenue, Toronto, Ontario, M4N 3M5, Canada
E-mail: {dchung,gawright,pradau}@swri.ca

Abstract. Real-time 2D MR technology is being developed to guide cardiac procedures; associated challenges include the relatively low resolution and image quality in real-time images. A proposed improvement is the alignment of the 2D real-time images with a reference volume to provide the spatial context with high resolution and SNR. A prototype contour tracking system was developed to maintain spatial alignment of a 4D prior volume to real-time MR images. Over an 8 second period of simulated motion, the tracking system was shown to maintain alignment with a displacement error of 3.1 mm in the left ventricular (LV) region of interest, versus displacement error of 17.9 mm without tracking.

1 Introduction

Cardiac interventional procedures such as myocardial stem cell delivery and electrophysiological (EP) ablation require a high degree of accuracy and efficiency. Real-time MR guided interventions would be enhanced by acquiring a 4D (3D + phase) volume prior to the procedure and aligning it to the 2D real-time images, so that corresponding features in the prior volume can be integrated into the real-time image visualization. Similar reference volumes have been proposed for interventional procedures for the abdomen and prostate [1, 2]. By means of the reference volume, further information could be integrated, such as a registered normal EP map with an ablation plan.

Image alignment is traditionally addressed by voxel-based registration algorithms that require 5 sec. or more processing time, however, real-time MR images are often acquired at 10-15 frames/sec. We propose a hybrid registration-tracking system that incorporates a real-time contour tracker, providing incremental scan-plane alignment transformations with high accuracy.

2 Method

Our contour tracker uses the *Condensation* algorithm, [3], to track the LV epicardial wall but forgoes the requirement to learn myocardial wall shapes. Instead, we used a customizable LV myocardium template [4, 5] that was preprocessed to indicate the shape of the LV epicardial wall for any arbitrary scan plane orientation.

The MR scanner reports patient ECG data and the scan-plane's absolute geometry, which were used to estimate the time point and slice in the 4D prior volume that is closest to the real-time scan-plane. A 2D mutual information image registration algorithm [6] calculates an improved initial scan-plane position from which the contour tracker begins execution.

In principle, the tracker is able to estimate any parametric deformation of the shape template, although in this prototype, 2D affine transformations were applied to align short axis images. The tracker generates samples of the affine state vector and measures the suitability of each sample by seeking edge features (from the Canny filter) that support the sample's proposed contour position. The best position compared with the edge map is adopted as the current state estimate.

Validation of the tracker was accomplished by simulating motion of images extracted from the prior volume so that motion transformations were known. The images were altered to appear as real-time images by smoothing, and adding Gaussian noise to achieve appropriate SNR [2]. The synthetic images were 128 x 128, with 1.64 mm/pixel. Three ranges of random, rigid motion were used to generate test sequences, assuming a frame rate of 10 Hz. The difference between the tracker-recovered affine transforms and the known motion was quantified by displacement errors in an LV region of interest (ROI).

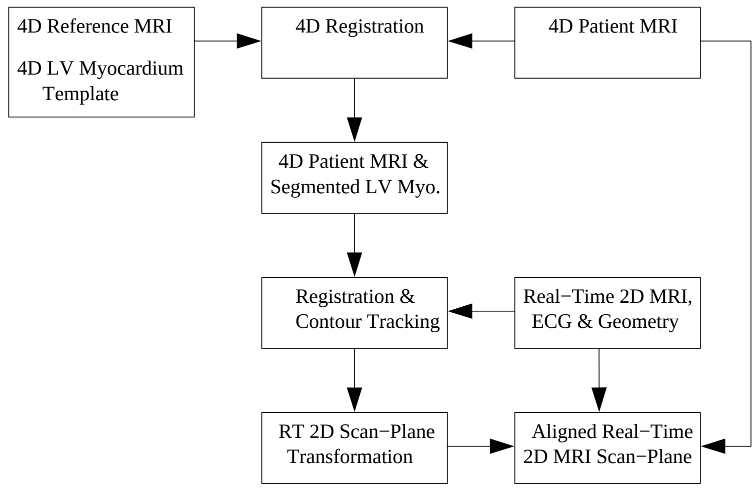

Fig. 1. Real-Time MR Scan-Plane Alignment System Diagram

3 Results and Discussion

Misalignment results indicate the mean misalignment of pixels in the ROI, averaged over 100 frames. The zero motion test case indicates the approximate limit of the tracker's mean alignment accuracy of 1.73 $\pm$1.05 mm. Mean pixel misalignment remains in the range of 2.6 mm $\pm$1.06 mm when realistic patterns of motion are simulated. This displacement arises from $\leq$ 2.5 mm translation and $\leq$ 1 degree of rotation between frames. Notably, after an 8 sec. period in the realistic test sequence, mean misalignment due to drift was 17.87 $\pm$2.57 mm without tracking, but only 3.08 $\pm$1.16 mm with tracking. A final test sequence simulates abnormally fast patient movements, and illustrates a smooth degradation in tracker performance.

Translation (mm/Frame)	Rotation (Deg./Frame)	Mean Misalign.	Std. Dev. Misalign.
0	0	1.73	1.05
0 - 2.5	0 - 1	2.67	1.06
6.5 - 8.5	0 - 2	3.30	3.36

Table 1. Mean pixel misalignment in the LV ROI (mm)

We intend to improve alignment accuracy and tracking robustness by simultaneously tracking the epicardial and endocardial LV walls, providing a more comprehensive constraint for the algorithm. This improvement would also allow us to perform realtime characterization of changes in myocardial function during intervention, by monitoring changes in wall thickening behavior.

References

1. Penney, G., Batchelor, P., Hill, D., Hawkes, D.: Validation of a two- to three-dimensional registration algorithm for aligning preoperative CT images and intraoperative fluoroscopy images. Medical Physics **28** (2001)
2. Fei, B., Duerk, J., Wilson, D.: Automatic 3D registration for interventional MRI-guided treatment of prostate cancer. Computer Aided Surgery **7** (2002) 257–267
3. Isard, M., Blake, A.: Condensation - conditional density propagation for visual tracking. International Journal of Computer Vision **29** (1998)
4. Wierzbicki, M., Drangova, M., Guiraudon, G., Peters, T.: Validation of dynamic heart models obtained using non-linear registration for virtual reality training, planning and guidance of minimally invasive cardiac surgeries. Medical Image Analysis **8** (2004)
5. Moore, J., Drangova, M., Wierzbicki, M., Barron, J., Peters, T.: A high resolution MRI heart model. In: Submitted to MICCAI. (2005)
6. Insight-Software-Consortium: ITK Toolkit. www.itk.org (2004)