Registering Real Time and Prior Image Data for MR Guided Interventions

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INTRODUCTION: Image guided radiofrequency (RF) ablations are an important clinical tool for the treatment of cardiac arrhythmias such as atrial fibrillation (AF) and ventricular tachycardia (VT). This minimally invasive procedure is often performed under X-ray guidance [1]. Recently, there has been a trend towards using previously acquired (prior) 3D MR roadmaps to improve the accuracy of targeting RF ablations [2]. Unfortunately, these prior roadmaps do not reflect the dynamics of the heart position due to respiratory motions that can cause displacements of up to 15-20 mm [3]. Here we propose a method, which performs a multi-resolution image based registration to correct for a full range of possible respiratory displacements up to 20 mm. The proposed method is then evaluated in terms of target registration error (TRE) and the overall computational time.

METHOD: 3D prior roadmap volumes are constructed through the acquisition of multi-slice 2D MR images for each of 3 healthy volunteers. Subsequently, a real-time (RT) 2D cine slice is obtained at the mid-section of the left ventricle (LV) using a slice prescription corresponding to a section of the prior data. Both prior and RT datasets are ECG gated to the mid-diastolic phase, and acquired in the end-expiration (EE) respiratory phase. This creates a controlled experiment, in which the optimal alignment is known between the prior and RT data. Subsequently, simulated rotations and translations along the 3 axes are performed to displace target landmarks (e.g. LV apex, papillary muscles, and aortic valve annulus) to 5, 10, 15, and 20 mm away, representing possible respiratory shifts. Various image based registration approaches are then applied to recover the known optimal alignment.

Image Acquisition: The proposed method was implemented on a 1.5T GE MRI scanner, and the scan parameters are as follows: prior MRI - multi-slice balanced SSFP sequence with resolution 1.36x1.36x8mm, TR/TE=2.7/1.3ms, views per segment = 16, flip angle=30°, FOV=35cm; RT-MRI - 2D spiral-bSSFP sequence, with resolution 2.3x2.3x8mm, TR/TE=6.8/1.5ms, flip angle=45°, FOV=35cm, 8 frames per second. All imaging data are acquired at the EE respiratory phase and are ECG gated.

Image Registration Algorithm: A multi-resolution 2D/3D rigid body registration algorithm is implemented to align the RT and prior datasets within a region of interest around the cardiac chambers. The image registration is performed in a coarse-to-fine manner, where the RT and prior datasets are registered on a coarse level (input images are down-sampled and interpolated), and then the optimal transform parameters obtained on the coarser resolution level are used as the initial starting point at the finer resolution level. In one case study, single metric experiments were performed, where the registration algorithm optimizes over sum of squared differences (SSD) or mutual information (MI) [4] across all resolution levels. This is compared with a single-resolution approach, where SSD or MI is only optimized over the finest (original) resolution level. Alternatively, a two-step multi-resolution approach is performed, where a similarity metric with a smooth cost function (SSD) is chosen on coarse levels to converge to near vicinity of the optimal solution, before switching to a metric with a sharp optimal peak (MI) at the finest resolution level. Cost function smoothness at different resolutions is illustrated in Fig. 1.

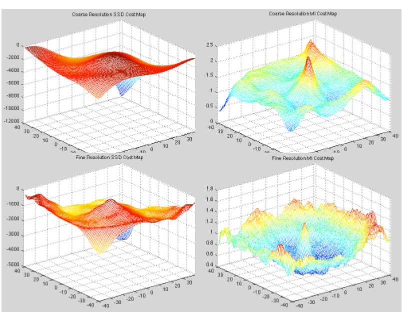

Fig. 1: Cost Function Smoothness. Top row shows negated SSD (left) and MI (right) measures at the coarse resolution level, while the bottom row shows the same similarity metric cost functions at the finest resolution.

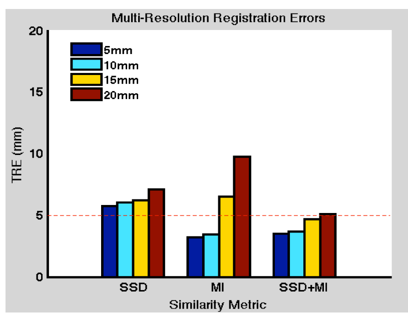

Fig. 2: Multi-Resolution Approach. Mean target registration errors are shown for initial displacements of 5, 10, 15, and 20 mm. Lowest TRE for high initial displacements is achieved via a 2-step metric approach.

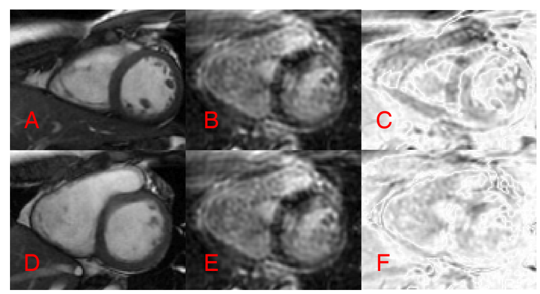

Fig. 3: Visual Registration Result. A) Prior image displaced by 20 mm; B) RT image; C) Difference image before registration, between A and B; D) Prior image after registration; E) RT image; F) Difference image after registration, between D and E.

RESULTS: In the validations of the image based registration method, a coarse-to-fine approach consisting of three resolution levels generally performed better than a single-resolution technique. Using a multi-resolution approach enabled the reduction of both the average TRE and computational time (e.g. in the case of the MI metric experiments, average TREs at 20 mm initial displacement were 16.9 and 9.8 mm, while registration times were 58.5 and 30.1 s for single and multi-resolution studies respectively). In the multi-resolution experiments, registration using SSD as a similarity metric across all resolutions performed better than MI at large initial displacements (>10 mm), while optimizing over MI across all resolutions performed better at lower initial displacements (<=10 mm) as illustrated in Fig. 2. In general, a two-step similarity metric (SSD and MI) registration approach worked well for the entire range of initial displacements, reducing the target registration errors from 5, 10, 15, and 20 mm down to a mean of 3.5, 3.7, 4.7 and 5.1 mm respectively (Fig. 2). The average computational time for the multi-resolution two-step approach is 29.3 s. A visual registration example between a RT and a prior roadmap image that was initially shifted 20 mm away from the optimal alignment is shown in Fig. 3.

CONCLUSIONS/DISCUSSIONS: We have presented an imaging based alignment method to potentially improve the targeting accuracy of interventional RF ablation procedures. The fastest and most accurate method uses a coarse-to-fine approach optimizing over SSD at coarse levels, since SSD yields the most smoothly varying cost function; once the registration process is in close vicinity of the optimal solution, the algorithm switches to MI to quickly reach the narrow optimal peak (Fig. 1). This reduces computational time and the probability of being trapped in a local optimum. The resulting lower TRE at high initial displacements compared to using SSD or MI alone suggests that the two-step metric optimization approach is more robust at high respiratory shifts, potentially leading to reduced targeting errors. Ongoing work will aim to further reduce overall registration time to facilitate real-time image fusion, which could be of great value for MR-guided procedures.

REFERENCES: [1] Rhode KS *et al.*, IEEE Trans Med Imag, 2005:24:1428-1440. [2] Dong J *et al.,* J Cardiovasc Electrophysiol, 2006:17:459-466. [3] Scott A *et al.,* Radiology, 2009:250:331-351. [4] Viola P *et al.*, Int J Comput Vision, 1997:24:137-154.