MRI Sequences and Registration Approaches for Respiratory Motion Correction in XMR-Guided Cardiac Catheterisations – Method and First Clinical Application

A. P. King[1], R. Boubertakh[1], K. S. Rhode[1], Y-L. Ma[1], P. Chinchapatnam[2], G. Gao[2], T. Tangcharoen[1], M. Ginks[1], D. J. Hawkes[2], R. Razavi[1], and T. Schaeffter[1]

[1]Division of Imaging Sciences, Kings College, London, United Kingdom, [2]Centre for Medical Image Computing, University College, London, United Kingdom

Introduction

We have previously described a system for image-guided cardiac catheterisations in a hybrid XMR imaging environment [1]. Real-time X-ray fluoroscopy images are fused with an accurately aligned MR-derived anatomical roadmap through a combination of system calibration and tracking. This system has undergone clinical validation in more than 50 cases and alignment accuracy has been found to be 2mm. However, respiratory motion typically introduces much greater errors than this, limiting the effectiveness of the roadmap for guidance and reducing the confidence of the cardiologist. In this abstract we describe a novel technique for correcting for respiratory motion that uses a patient-specific MR-derived motion model. We discuss different possible MR imaging sequences and registration approaches for forming this motion model and present results from four volunteer datasets and three patients who underwent XMR-guided cardiac catheterisations.

Method

Two different MR scans are required to form the motion model: a 3-D high-resolution MRI for the anatomy and a dynamic near real-time scan to determine the respiratory motion. For the high-resolution image, we used a free breathing 3-D balanced TFE sequence, acquired at diastole during end-expiration (typically, 120 slices, TR=4.4ms, TE=2.2ms, flip-angle=90^o, acquired voxel size 2.19x2.19x2.74mm^3, reconstructed to 1.37x1.37x1.37mm^3, 256x256 matrix). For the volunteers three additional high-resolution images were acquired at different respiratory positions for validation. For the dynamic scan, we tested two different MR sequences:

- *Low resolution 3-D*: 3-D TFEPI, typically, 20 slices, TR=11.75ms, TE=5.84ms, flip-angle=20^o, acquired voxel size 3.81x4.27x8.0mm^3, reconstructed to 2.22x2.22x4.0mm^3, 144x144 matrix, 100 dynamics
- *High resolution 2-D*: Multislice balanced TFE, typically, TR=2.74ms, TE=1.37ms, flip-angle=60^o, acquired voxel size 1.78x1.75x8.0mm^3, reconstructed to 1.09x1.09x8.0mm^3, 320x320 matrix, 100 dynamics

The low resolution 3-D sequence has been previously shown to be effective in correcting for respiratory motion during MR image acquisition in coronary angiography [2]. The high resolution 2-D sequence was tested because in our experience the dominant cardiac respiratory motion parameters are the inferior-superior (I-S) and anterior-posterior (A-P) translations, the I-S scaling, and the medial-lateral (M-L) axis rotation. Similar findings have been reported in [3]. All of these parameters can be accurately estimated from high-resolution sagittal slices. For both dynamic sequences, a pencil-beam navigator was applied on the right hemi-diaphragm immediately before and after each acquisition. The average of these lead and trail navigators was used in forming the model. The motion model was constructed by registering each dynamic acquisition to the high-resolution volume using an affine intensity-based algorithm that aims to maximise the normalised mutual information between the images in the region of overlap. The affine registration parameters were modelled using second-order polynomial functions of the navigator value [2]. We modelled inspiration and expiration phases separately to capture the hysteresis effects that have been reported in [4]. Furthermore we constrained the curves so that they meet at the extremes of inspiration and expiration. For the registration, we tested two different approaches: a full affine registration and a constrained registration that allows variation only in the dominant modes of motion: the three translations, the S-I scaling and the M-L axis rotation. In order to use this model to update the roadmap within the XMR image-guidance system, the diaphragm was automatically tracked in X-ray fluoroscopy images. We gated the X-ray images at diastole by synchronising X-ray image acquisition with the electrocardiogram signal. The motion corrected roadmap was continually displayed, superimposed on the X-ray images.

Results

In the volunteer datasets validation was performed by using the motion model to predict the locations of 10 manually localised anatomical landmarks in the three additional high-resolution MR images. Figure 1 summarises the target registration errors (TRE) over all four volunteers. For the clinical cases, 2-D errors were assessed by overlaying a rendering of a vessel onto X-ray images that showed a catheter positioned inside the vessel. For Patient A the error at full inhale was reduced from 13.3mm to 2.8mm, for Patient B from 5.1mm to 3.9mm, and for Patient C from 7.5mm to 2.2mm. Figure 2 shows the images used for Patient A.

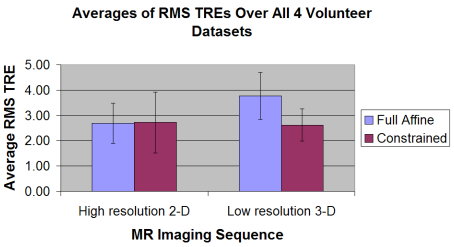

Figure 1 - Comparison of MR Imaging Sequences and Registration Approaches for Motion Model Formation

Discussion

We have demonstrated the construction of a patient-specific cardiac respiratory motion model from MRI data and its application in an image-guidance system for cardiac catheterisations. Results have shown that accuracy can be improved by using a high resolution 2-D dynamic sequence or a constrained registration approach, rather than a low resolution 3-D sequence with full affine registration. The improved alignment accuracy provided by the technique we have described has the potential to increase the confidence of the cardiologist when performing image-guided cardiac catheterisations, reducing procedure time and X-ray dose. The model also has possible application in motion-corrected MR image acquisition.

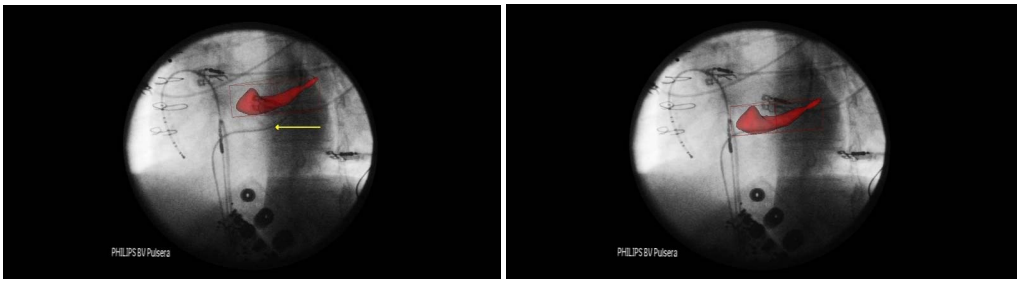

Figure 2 – MRI-derived overlay of coronary sinus (CS) on X-ray image showing a CS catheter (indicated by arrow) – before (left) and after (right) motion correction.

References

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