Three-Dimensional Catheter Tracking Using Real-Time Volumetric Imaging

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Introduction: Passive catheter visualization in MR guided cardiac catheterization is limited by ambiguity in catheter identification as well as the need for manual tracking. In this paper, we present a technique for passive tracking of standard balloon angiographic catheters using real-time volumetric MR imaging on a 32 channel scanner. Prior to catheter insertion, real-time 3D reference volumes are acquired, sampling the cardio-respiratory space. After catheter insertion, the location of the tip of the catheter can be automatically identified in real-time interventional volumes by: 1) calculating difference images by subtracting the current interventional volume from the reference data set, 2) finding the closest reference volume using a similarity measure metric, 3) localizing the catheter in 3D from the selected difference image using simple image analysis operators. Applied to a healthy volunteer with a vessel phantom, this technique was able to track the 3D location of the catheter tip in the presence of both cardiac and respiratory motion.

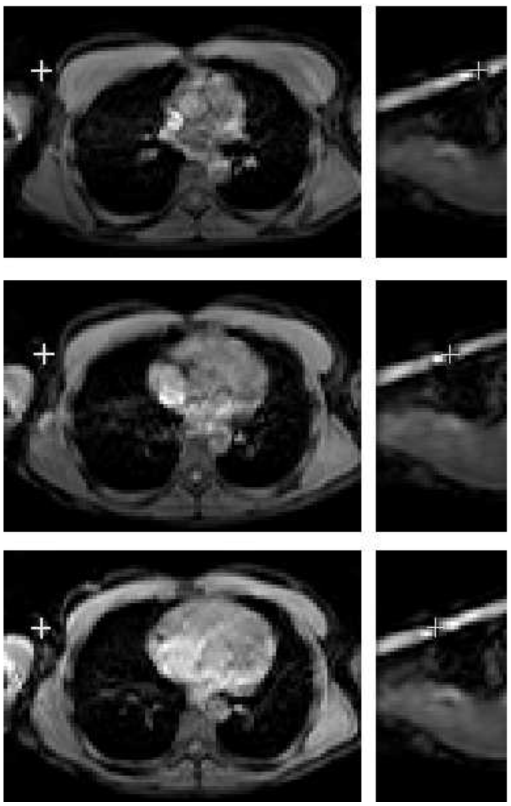

Figure 1: Sagittal and transverse anatomical views during catheter manipulation.

Methods: A healthy male volunteer was imaged on a 1.5T Philips Achieva equipped with 32 independent receive channels and using a custom built 32 channel coil. A flexible plastic tube, filled with manganese chloride solution, was attached to the volunteer's chest.

A reference data set, consisting of 1000 free-breathing 3D whole-heart volumes, was acquired over 4 minutes prior to catheter insertion. Each volume was acquired in 213ms, a temporal resolution of over four volumes per second. A single shot TFE-EPI sequence was used (FOV 360x255x131mm^3, TR 15.2ms TE 7.5ms, flip angle 15^o) in combination with 2D-SENSE (factors of 3x2) and half-Fourier sampling, reconstructed to 3.75x3.75x3.75mm.

To simulate catheter manipulation, a balloon angiographic catheter was then introduced in the tube and the balloon inflated. The catheter was manoeuvred along the tube whilst an interventional data set consisting of 50 free-breathing volumes was acquired. Subsequent image analysis was performed off-line.

For each interventional volume, the closest reference volume was determined. This was achieved by subtracting each reference volume in turn from the interventional volume, and selecting the reference volume with the minimum sum of squares residual in the difference image. The balloon's signal void was localized within the subtracted volume by automatic thresholding. The 3D centroid of this thresholded region localized the catheter tip. For each frame in the dynamic sequence, the automatically identified location of the catheter tip was overlaid as a cross-hair on a reformatted slice passing through the tip.

Results: Figure 1 shows transverse and sagittal slices during catheter manipulation. The tip of the catheter, displayed as a cross-hair, can be clearly seen as it is progressing inside the tube. Figure 2 illustrates the three-dimensional nature of the technique: the tip of the catheter has been successfully localized and tracked as shown in the three orthogonal views.

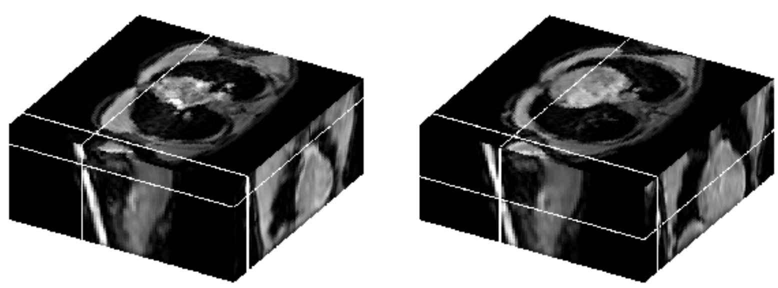

Figure 2: Volume localization of the catheter tip in three orthogonal reformatted slices at two consecutive time frames.

Conclusions: We demonstrated the feasibility of an adaptive subtraction technique that allows safe and automated 3D catheter tip tracking. This technique relies on fast real-time acquisition of 3D data using high SENSE factors. The cine frames and movies of the automatically identified catheter location and corresponding anatomy clearly highlight the technique's ability to track the catheter tip's trajectory in 3D. The main obstacle to be surmounted before this technique could be applied to real-time tracking in patients is the substantial acceleration of image reconstruction so that the image can be made available in the scanner room with a low latency. We have however provided proof-of-concept that this technique can be used for passive tracking in the presence of cardio-respiratory motion.