Technique for wireless position tracking of intravascular catheters: Performance evaluation in a vessel phantom

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Introduction/Purpose

Small tuned radiofrequency coils have already been proposed as fiducial MR markers for various purposes [1]. Due to the local amplification of the B_1 field, these inductively coupled RF (ICRF) coils give a high signal even after low flip angle excitation while the background signals remain relatively low. Recently, a morphological image processing technique based on 2D Gaussian template fitting has been proposed that allows automatic localization of such markers [2]. The purpose of this work was to implement a catheter-mounted marker design and to evaluate the performance during tracking experiments in a vessel phantom.

Materials and Methods

Two ICRF coils were tuned to the resonance frequency of a 1.5 T MRI scanner and mounted on a commercial 6F catheter (Balt Extrusion, France, Fig. 1). Localization in 3D was based on a morphologic analysis of the signal profiles (2D Gaussian fitting) on projection images (slice thickness ST=300 mm) from three orthogonal views (balanced SSFP: square matrix MX=64, square 300-mm FOV, TR/TE=101.3/1.15 ms, partial Fourier PF=6/8, bandwidth BW=1390 Hz/pixel) [2]. In an independent experiment, the absolute localization accuracy for these parameters has been estimated to be ≈1.0 mm. To determine the reliability of the tracking technique, the catheter was imaged continuously on seven different days (n=1034) while being moved inside an anatomical vessel phantom (Fig. 2) and localized retrospectively (3 GHz Pentium CPU). In one series, the determined marker positions were used to interactively define the oblique geometry (between sagittal and transverse) of anatomical MR images (b-SSFP, MX=128, square 150-mm FOV, TR/TE=292.4/2.14 ms, PF=4/8, BW=1085 Hz/pixel, ST=20 mm, flip angle FA=70°) containing the catheter (Fig. 4). The contrast-to-noise ratio was determined by $CNR=(S_M–S_B)/S_B$, with S_M as maximum marker and S_B as background signal averaged over a fixed ROI. The catheter was also placed on a volunteer's abdomen to evaluate marker discrimination over an anatomical background.

Results

A flip angle of 0.3° provided sufficiently high CNR (0.7-6.3, depending on the catheter's exact position and orientation) for marker detection and was used throughout all series. The catheter (both markers) was successfully localized on 1006 of 1036 cases, requiring an average CPU time of 46 ms. Fig. 3 shows the successful localization over an anatomical background. Two snapshots of the tracking MRI series are shown in Fig. 4. Full 3D localization including image acquisition took ~350 ms.

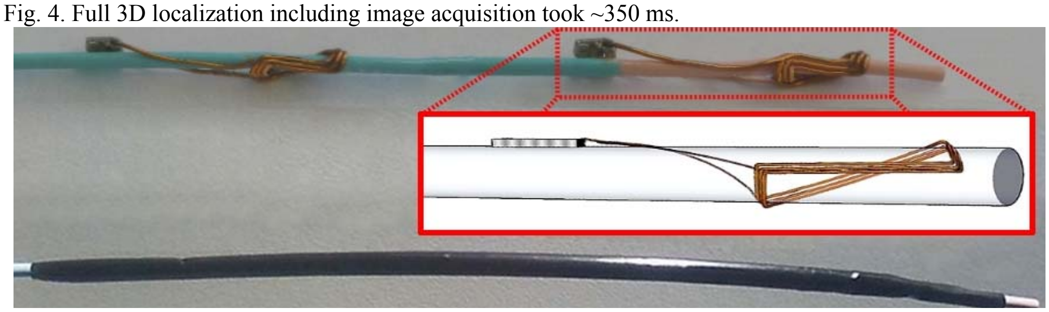

Fig. 1: Two inductively-coupled RF coils tuned to the resonance frequency of the MR scanner (63.8 MHz) mounted on a commercial 6F catheter. Schematic (inset) and actual (zoomed area) coil design with three non-planar turns of a 0.3-mm insulated copper wire and a ceramic chip condensator. Bottom photo shows the tested design with the coils wrapped by a (medically grade) heat shrink tubing (Ø≈3.3 mm).

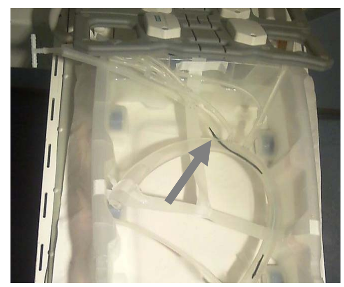

Fig. 2: Experimental setup with vessel model (silicone tubing) in water bath, receive body array coil, and inserted catheter (arrow).

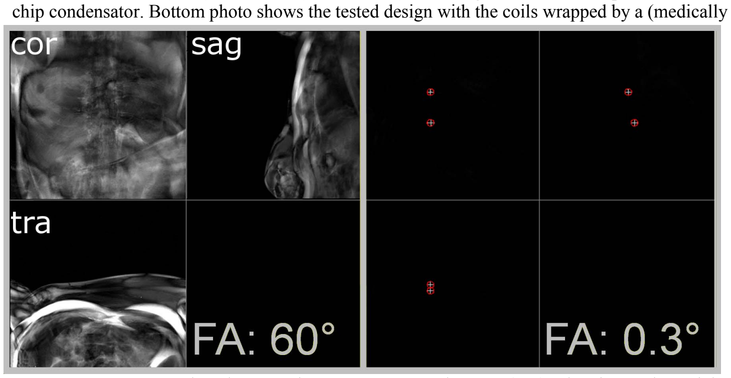

Fig. 3: **Left:** Marker b-SSFP images at "normal" FA (60°) showing substantial background signals. **Right:** Same experiment at low flip angle (0.3°) with minimal background signals. The resulting 3D marker coordinates are shown as red circles.

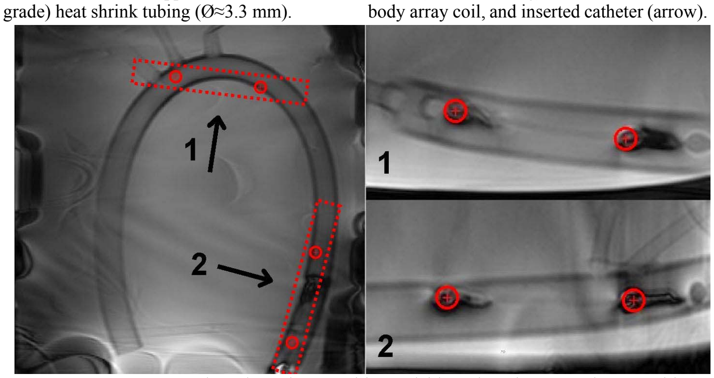

Fig. 4: **Left:** Coronal roadmap image with overlaid markers in two catheter positions. **Right:** Oblique anatomical "tracking" image (cropped) showing details of model arteries branching off the model aorta (red dashed box: slice geometry, arrow: viewing direction).

Discussion and Conclusion

The continuously measured 3D position may be overlaid on an intraprocedurally acquired roadmap (~3 updates /s) or used to define the geometry of actual MR scans displaying the local anatomy around the catheter in near realtime. The design of a realtime pulse sequence with automatic marker localization followed by a properly aligned anatomical image would allow a relatively fast tracking. In conclusion, an intravascular catheter could be tracked in a vessel phantom in near-realtime using a morphological analysis of the MR signals of catheter-mounted ICRF coils.

References [1] M. Burl et al., MRM 1996;36:491 [2] H. Busse et al., JMRI 2007;26:1087