Performance and accuracy of a morphological MR marker localization at reduced spatial resolutions: results from simulated and real marker images

G. Thörmer[1], N. Garnov[1], J. Haase[2], T. Kahn[1], M. Moche[1], and H. Busse[1]
[1]Diagnostic and Interventional Radiology, Leipzig University Hospital, Leipzig, Germany, [2]Physics and Geosciences Department, Leipzig University, Leipzig, Germany

Introduction/Purpose

Interventional guidance and tracking of MR devices rely on the proper visualization and localization of MR-visible structures or markers. Wireless techniques are relatively easy to implement and less prone to potential hazards but typically do not provide the high update rates as active techniques because localization is performed on fully reconstructed images. Different solutions for image-based localization have already been proposed that work with high spatial resolutions [1-3]. In this work, we used inductively coupled RF (ICRF) coils as MR markers and a 2D Gaussian fitting routine for marker localization and systematically explored the influence of the underlying pixel size (PS). The goal was to evaluate the performance (precision, accuracy and speed of localization) of such an approach for reduced spatial resolutions. Both simulated and scanned MR marker images have been processed to differentiate between imaging and localization contributions to the overall accuracy.

Materials and Methods

An ICRF coil was wound around a 4-mm-diameter glass tube containing tap water (Fig. 1) and tuned to the resonance frequency (63.8 MHz) of a diagnostic 1.5T MRI (Siemens Symphony) using a ceramic chip capacitor. By inductive coupling with the integrated body coil–used for RF excitation and signal reception–this micro coil generates a high contrast at very low flip angles [1]. Localization in 3D was based on 2D Gaussian template fitting and subsequent matching of the resulting peak positions in three orthogonal projection images using a balanced SSFP sequence (FOV=300 x 300 mm^2, ST=300 mm, FA=0.3°). Keeping the scan geometry constant, acquisition matrix size (MX), k-space sampling (partial Fourier factor PF), and receiver bandwidth (RBW) were varied to investigate the localization performance at different spatial/temporal resolutions (Tab. 1). By translating a marker along both ±x (left-right) and ±z (head-feet) axes on a grid phantom (spacing=10.0 ± 0.1 mm) the localization accuracy was estimated in the ±100 mm range around the isocenter as a function of spatial resolution. The mean (n=220) localization time was calculated on a 3 GHz Pentium CPU. In order to characterize the localization technique in the absence of imaging or hardware-related errors, the same analyses were performed on 40.000 synthetic (noisy) marker profiles that were overlaid on an anatomical background image (Fig. 2).

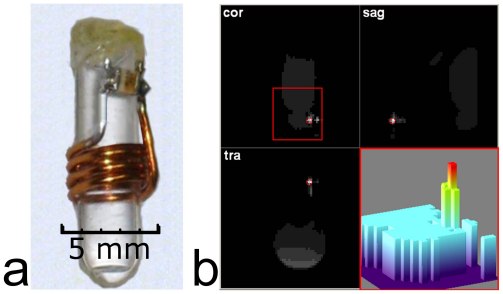

Fig. 1: a) ICRF marker coil. **b)** Successful subsecond 3D localization (red circles). Inset shows 3D signal profile over bottle background at a large pixel size (4.7 mm). Note the faint background at a flip angle as low as 0.3°.

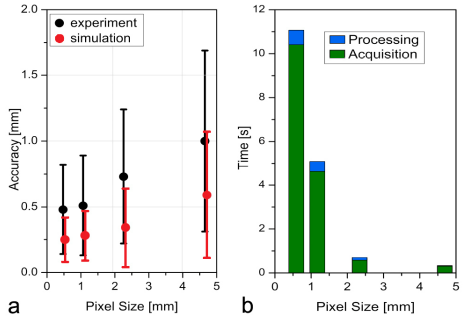

Fig.3: a) Average 3D localization errors and corresponding mean variation increasing with pixel size. The different errors observed for experimental and synthetic marker images are attributed to the hardware and imaging-related contributions. **b)** Localization times as a function of spatial image resolution (pixel size).

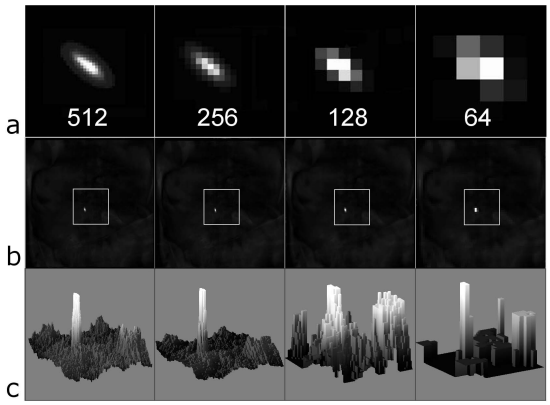

Fig. 2: a) Synthetic MR marker signals at different spatial resolutions. Numbers indicate (square) matrix size. **b)** Simulated markers superimposed on an anatomical background image. **c)** 3D surface plots of simulated marker images illustrating the signal intensities and distributions for different spatial resolutions (plots correspond to square ROIs in 2b).

MX PS [mm]	PF, RBW [Hz/pix] TR, TE	Axis	μ [mm]	σ [mm]	max [mm]
512	8/8, 220	r_x	0.44	0.34	0.93
0.59	3471 ms	r_z	0.58	0.35	1.01
	2.82 ms	**r**	**0.49**		
256	8/8, 220	r_x	0.45	0.36	1.19
1.17	1541 ms	r_z	0.65	0.43	1.73
	2.60 ms	**r**	**0.51**		
128	4/8, 765	r_x	0.69	0.52	1.58
2.34	195.2 ms	r_z	0.82	0.49	1.52
	1.20 ms	**r**	**0.73**		
64	6/8, 1395	r_x	0.94	0.58	1.53
4.69	101.3 ms	r_z	1.12	0.92	2.81
	0.91 ms	**r**	**1.00**		

Tab. 1: Summary of the statistical data (μ, σ, max) of the absolute deviations in the positional displacement (r) between MRI-derived and physical position on the marker board along x- and z-axes and their weighted average $r=(2r_x+r_z)/3$.

Results

Fig. 2 shows synthetic MR marker signals calculated for different spatial resolutions. The results of the experimental accuracy assessment are summarized in Tab. 1. The total 3D localization errors can be compared with the results of the simulation (Fig 3). At MX=64, the average CPU time was 46 ms which provides an accuracy of ≈1 mm for a full localization (including marker data acquisition, see Fig. 1b) in ≈350 ms.

Discussion and Conclusion

The time needed for the full acquisition of three 2D localization images was substantially reduced by sparse spatial (large pixel sizes) and partial k-space sampling. The moderate 3D errors obtained for the fastest sequence used here demonstrate that image-based position discrimination does not necessarily require highly resolved base images for marker detection. In conclusion, the presented morphological signal processing technique may either be used for device monitoring (tracking) with several updates per second at reduced spatial resolution or for purposes where a higher accuracy is desired such as patient registration or other position/orientation assessments (e.g. respiratory excursion).

References [1] H.Busse et al., JMRI 2007;26:1087, [2] S. Patil et.al., MRM 2009;62:935 [3] A. de Oliviera et al., MRM 1996;36:491.