Dynamic 3D Localization in Real Time using Spatial Phase-Contrast MRI

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Target Audience: Interventional MRI, stereotactic surgery, 3D localization

Purpose: As recently demonstrated, spatial information may be encoded as a differential phase similar to the principles underlying velocity-encoded phase-contrast MRI when a respective pair of gradients is applied along a perpendicular dimension and if this dimension contains a MRI-visible object at only one spatial location [1]. The situation applies to 3D mapping of planar (2D) structures with only two projection images and different spatial phase-encoding gradients. A combination with highly undersampled radial FLASH and image reconstruction by regularized nonlinear inversion [2,3] allows for serial 3D mapping in real time. If the object is restricted to a linear (1D) structure its position can be localized even faster by the acquisition of only three phase-encoded projections.

Methods: Dynamic spatial phase-contrast MRI (Fig. 1a) acquires series of two interleaved projection images with and without a monopolar phase-encoding gradient Gpc – instead of a bipolar gradient as used for phase-contrast MRI of blood flow in real time [4]. Corresponding phase difference maps refer to the positions of the object along the phase-encoded third dimension.
For 3D localization of linear (1D) structured objects only three frequency-encoded MRI signals (non-selective excitation) with two perpendicular spatial phase encodings (Fig. 3) are required leading to a temporal resolution of less than 10 milliseconds. All studies were conducted at 3T (TIM Trio, Siemens Healthcare, Erlangen, Germany) using a standard 32-channel head coil.

Results: Undersampled radial FLASH (2 × 11 spokes, TR/TE = 2.0/1.3 ms, flip angle 12^0, nonselective excitation) in conjunction with regularized nonlinear inversion [2,3] resulted in 3D MRI movies at 44 ms resolution (Fig. 2). Selected 3D representations depict a moving hand (Fig. 1b) and a water-filled "catheter" (Fig. 1c) which is manually retracted from a guiding tube attached to a cone (every 20 or 70th frame, respectively). The bottom planes show the original (color-coded) 2D phase-contrast projection maps.

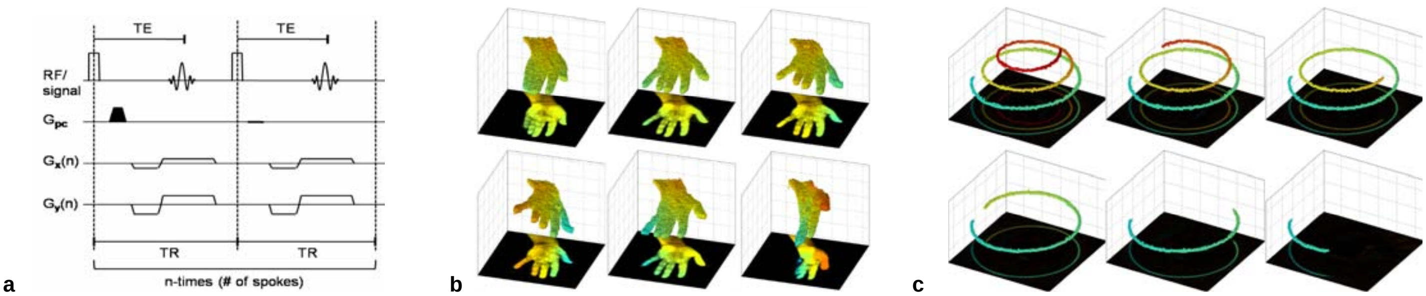

Fig.1: (a) Localization by two radial projection images: (b) selected 3D-representations from a movie of a tilting hand, and (c) retracting a waterfilled tube.

The spatial localization of a linear object was accomplished by recording 3 signals (TR/TE = 1.67/1.15 ms, flip angle 6^0, 2mm linear resolution nonselective excitation) resulting in a temporal resolution of 5ms (200 frames per second) for a rotating banana (Fig. 2b) and 12ms (80 frames per second, TR/TE = 4.0/2.0ms, flip angle 8^0, 1.5mm resolution) for three water-filled samples attached to a rotating plate (Fig. 2c).

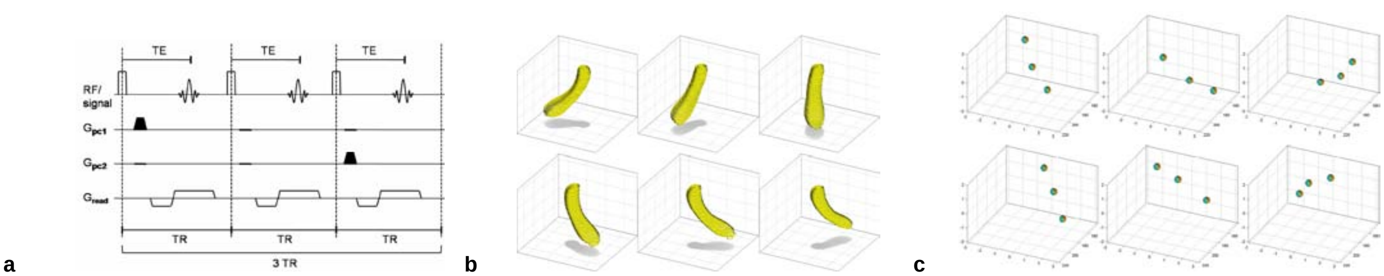

Fig.2: (a) Localization of linear objects by three projections: (b) selected 3D-representations from a movie of a rotating banana (every 20th frame), and (c) three water-filled samples attached to a rotating plate (every 20th frame).

Conclusion: Spatially encoded phase-contrast MRI may be used for dynamic 3D localization of 1D and 2D objects in real time. The approach may bear considerable potential for future applications in interventional MRI scenarios.

Reference: [1] KD Merboldt et al, MRM 2011, 66:950-956; [2] M Uecker M et al, MRM 2010, 63:1456-1462; [3] S Zhang et al. JCMR 2010, 12-39; [4] AA Joseph et al. NMR Biomed 2012, 25: 917-924;