Motion-Corrected Single Shot Fast Spin-Echo MRI using Prospective Motion Tracking and Retrospective Super-Resolution Volume Reconstruction

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Introduction

Subject motion frequently prevents successful MR imaging. Despite progress in prospective motion correction in MRI [1-3], motion correction remains a practical issue, and compensation techniques have been limited by the type and amount of motion that can be compensated for, the dependency on the scanner platform, the need for pulse sequence modifications, and/or difficult setup. Consequently, sedation and anesthesia are routinely used in imaging newborns, children, and adult patients who cannot hold still in the scanner. Half-Fourier acquisition single shot fast spin echo MRI (aka HASTE by Siemens and SSFSE by GE) is a fast imaging technique used to acquire high-quality high-resolution T2-weighted 2D slices in the presence of subject motion. Nevertheless, severe inter-slice motion artifacts appear in out-of-plane and 3D views of HASTE scans, rendering the images unsuitable for 3D assessment. Here we present a novel technique for motion-corrected volumetric MRI from multiple orthogonal HASTE scans through sensor-based prospective motion tracking and retrospective volume reconstruction. Our technique has a simple setup and is platform independent, and thus enables motion robust 3D T2-weighted imaging of moving subjects.

Fig. 1: The sensor.

Methodology

Our approach to obtain motion-corrected volumetric MRI utilizes motion tracking information from a three-dimensional miniature magnetic field sensor (shown in Fig. 1) to estimate the relative motion of the subject at each HASTE slice acquisition. An example of motion tracking results is shown in Fig. 2. The sensor consists of three orthogonal pairs of pick up coils, and its location and orientation are calculated in real-time. The location of the imaged object at each slice acquisition is estimated and then used for volumetric reconstruction. We use a slice acquisition model which defines how the slice represents a section of the imaged object, and utilizes the geometry of the slice based on the location of the subject, the slice orientation encoded by the direction cosines matrix, and the slice thickness, origin, and profile [4]. Super-resolution volume reconstruction [4] is formulated as the inverse problem of finding a 3D volumetric representation of the imaged object given the imaged slices, based on the slice acquisition model and motion parameters. We use a maximum a posteriori (MAP) estimation technique developed in [5] to solve this inverse problem.

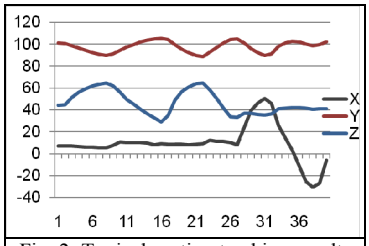

Fig. 2: Typical motion tracking results for 40 HASTE slices. Only translation parameters are shown (in millimeters).

Data

HASTE scans for human subjects as well as pineapple and water phantoms were performed on Siemens Trio 3-Tesla scanners, with TR=1500 ms, TE=83 ms, slice thickness of 4 mm, and in-plane resolution of 1 mm. Each experiment involved one set of HASTE scans with motion and one set without motion. Each set involved six HASTE scans (two in each slice select direction with half-slice shift proscribed imaging). Reference volumes were reconstructed from the set of HASTE scans without motion using the technique discussed in [5], and were used for quantitative evaluation.

Results

Quantitative evaluation was performed by computing mean square error (MSE) and peak signal to noise ratio (PSNR) metrics [4] between the images and the reference volumes. Table 1 reports the average metrics for six phantom and volunteer experiments, for the originals (HASTE scans), the average of six HASTE scans in each set (Averaging), and our motion-corrected MAP reconstructed (MCMAPR) volume. The volumetric images reconstructed using MCMAPR showed the lowest variation from the reference volumes (i.e. lowest MSE and highest PSNR) in all individual phantom and volunteer experiments. The best average performance values are highlighted with bold text in Table 1. Fig. 3 shows sample slices of the volumes obtained using one of our volunteer subject experiments. An extrinsic marker attached to the forehead is also observed in these images. Inter-slice motion artifacts are visible in the original HASTE scan in (a). These artifacts caused blurriness in the image obtained by averaging in (b). The motion effects have been compensated in the volumetric image obtained from MCMAPR in (c). This image is sharp and presents the anatomic details in 3D.

TABLE 1 – AVERAGE PERFORMANCE METRICS

	PHANTOMS		VOLUNTEERS	
	MSE	PSNR	MSE	PSNR
Originals	30.0	30.0	135	23.0
Averaging	23.2	31.6	96.3	25.6
MCMAPR	**18.5**	**36.1**	**72.7**	**27.8**

Discussion

By using prospective motion tracking and retrospective volume reconstruction we have developed a platform-independent technique for T2-weighted volumetric MRI of moving subjects. This technique enables motion robust imaging, and may enable a reduction in the use of sedation in imaging newborns, children and adults who cannot hold still in the scanner.

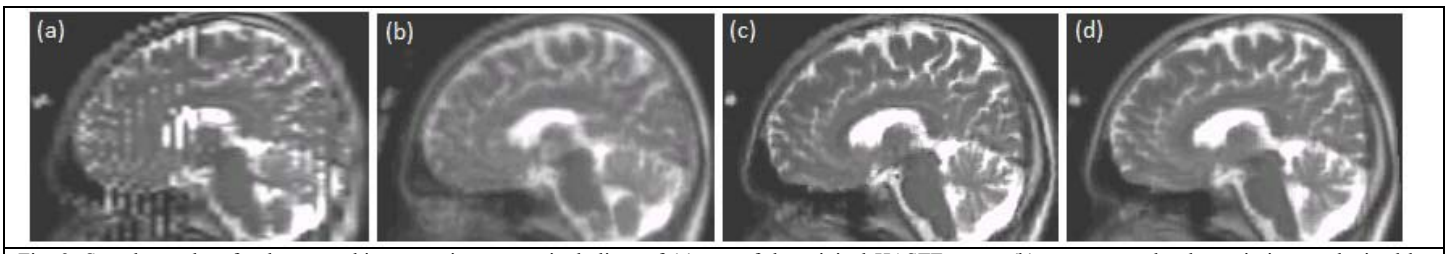

Fig. 3: Sample results of volunteer subject experiments; sagittal slices of (a) one of the original HASTE scans, (b) reconstructed volumetric image obtained by averaging six HASTE scans (without motion correction), (c) reconstructed volumetric image using our technique (MCMAPR), and (d) reference volumetric image.

References - [1] J.M. Maclaren et al. MRM 63:162-170, 2010 ; [2] N. White et al. MRM 63:91-105, 2010 ; [3] L. Qin et al. MRM 62:924-934, 2009 ; [4] A Gholipour et al. TMI 29:1739-58, 2010 ; [5] A Gholipour et al. MICCAI 13:109-116, 2010.

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