Real Time Prospective Motion Correction for High Resolution In Vivo MRI Using an Optical Motion Tracking System

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Introduction

Even small subject motions can degrade the image quality especially in high-resolution MRI. For head imaging the overall imaging time is limited by the subject's ability to maintain the same head position. This time is on the order of minutes and may be dramatically reduced in a case of pathology. Projection reconstruction(1) or PROPELLER(2) methods are known to be less prone to motion artefacts. The sensitivity of standard 2D and 3D imaging methods to motion may be reduced by use of the navigator echoes, such as orbital (3) or spherical (4) navigator methods. Navigators, however, not only lengthen the measurement, but also require additional excitation RF pulses to be incorporated into the sequence, which disturbs the steady state. Here we demonstrate the possibility of interfacing the MR scanner with an external optical motion tracking system, capable of determining object's position with sub-millimetre accuracy at high update rate. The proposed approach uses this motion information to update in real time the position of the imaging volume during the acquisition of *k*-space data. Such methods have previously been proposed for fMRI. The purpose of the study is to evaluate the applicability of prospective motion correction for high-resolution brain imaging in the presence of strong subject motion.

Methods

The prospective motion correction technique was implemented on a Magnetom Trio 3T system (Siemens Medical Solutions, Germany). The product GRE and TSE sequences were extended to enable real-time line-by-line update of the imaging volume position. The acquisition of single k-space lines was rejected and repeated if motion within a TR exceeded a predefined threshold. A stereoscopic optical motion tracking system (ARTrack1, Advanced Realtime Tracking, Germany) was connected to the internal Ethernet of the MR instrument. The communication with the tracking system was implemented directly on the measurement control unit of the scanner. The tracking system was capable of measuring positions of multiple targets fitted with retro-reflective spheres with the accuracy of 0.1mm (RMS) and an update rate of 60Hz. The measured delay in the entire feedback loop was 32±1ms. For *in vivo* imaging mouthpieces fitted with reflective spheres were used (Fig. 1). Experiments in humans were performed in accordance with local IRB regulations. No head fixation pads were used to enable exaggerated motion during the volunteer experiments.

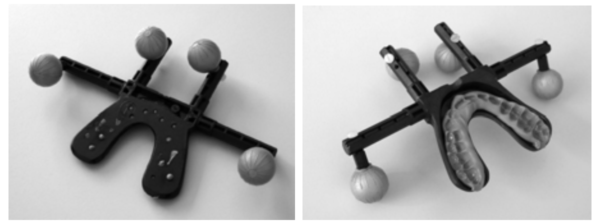

Fig.1. *Mouthpiece with attached reflective spheres and dental cast*

Results

The results of the imaging experiments performed with the 2D spin echo (SE) and 3D gradient echo (GRE) sequences are presented in Figs. 2 and 3, respectively. During the acquisition of images 2b, 2d, 3b and 3d the volunteer was instructed to perform series of fast head rotations with the amplitude of about 10° to 15°. Motion parameters were recorded and were comparable in the respective experiments. In case of stationary imaging no apparent quality loss is associated with enabling the motion correction (compare images a and c in Figs. 2 and 3). In presence of motion, prospective correction (images d) effectively suppresses motion artefacts. Nevertheless, a certain reduction of image intensity and SNR may be observed in images 2d and 3d in comparison to the respective images acquired in absence of motion.

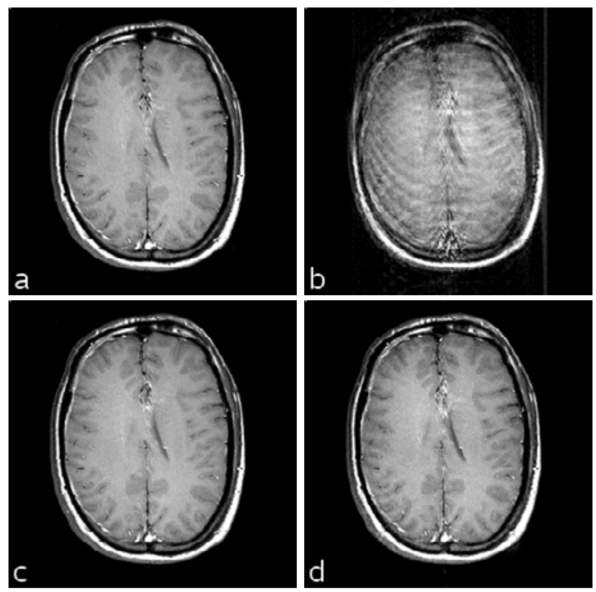

Fig. 2. *2D spin echo T_1-weighted images acquired with and without prospective line-by-line motion correction: (a) no intended motion, correction deactivated; (b) with motion, no correction; (c) correction activated without motion; (d) corrected images acquired in presence of motion comparable to that of (b). Measurement parameters: in plane resolution 0.88mm², slice thickness 4mm, single slice, TE/TR=12/500 ms, motion rejecting threshold 0.3mm.*

Discussion

Reported here is the first successful implementation of an external prospective real time motion correction for high resolution MRI. The proposed approach is compatible with a multitude of sequences and in it self does not compromise the scanning efficiency. However, it was found to be advantageous for the image quality to reject the data acquired in during rapid motions. For the images 2d and 3d acquired in the presence of motion the data rejection rates amounted to 20% and 1% respectively. The higher rejection rate for SE imaging is due to the longer TR. The reduction of SNR observed in the corrected images in presence of strong motion is due to k-space inconsistencies introduced by several factors. There are position-related factors such as B_0 and B_1 field inhomogeneities and gradient non-linearities. Motion-related factors include velocity-induced phase effects and the finite latency of the correction chain. Motion-related effects may be effectively addressed by incorporating the knowledge of the object position corrected for the system latency into the image reconstruction, similarly to the recently proposed postprocessing-only correction(5). The combination of the prospective and retrospective corrections will make high resolution imaging feasible in the most uncooperative subjects. It is to be noted, that the prospective motion correction proposed here may use any arbitrary means of the motion detection as long as it is fast and accurate.

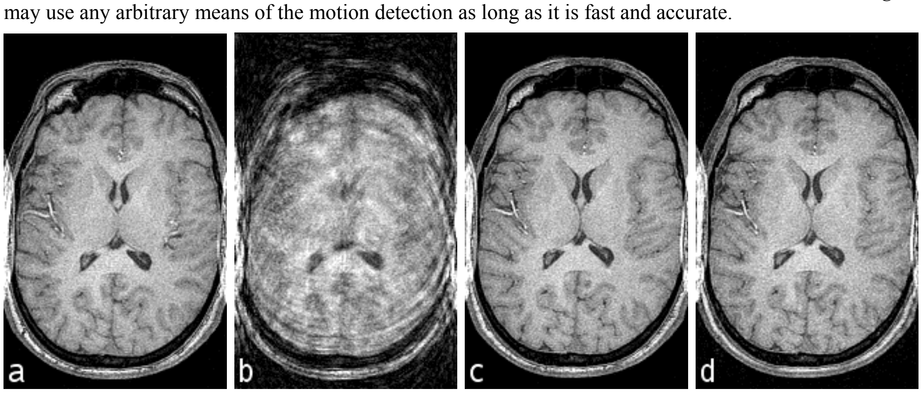

Fig. 3. *3D T1-weighted gradient echo images acquired with and without motion correction: (a) no intended motion, correction deactivated; (b) with motion, no correction; (c) correction activated without motion; (d) corrected images acquired in presence of motion comparable to that of (b). Measurement parameters: resolution 0.88mm3, TE/TR = 1.7/10 ms, flip angle 10°, motion rejecting threshold 0.3 mm, with H-F frequency, A-P phase and L-R partition directions).*

References

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