First in vivo results using decoupled projection based shimming

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Introduction: Due to its simple readout trajectory, fastness and sensitivity to BOLD contrast, the Echo Planar Imaging sequence (EPI) is the method of choice for functional Magnetic Resonance Imaging (fMRI). The price for the increased T2* sensitivity is, in the case of EPI, strong geometric distortions. While static distortions can be measured prior to the fMRI experiment, e.g. [1], shim changes caused by scanner instabilities or physiological noise, such as breathing or motion, can lead to varying distortions during the experiment. For fast measurement of shim changes projection based methods have been proposed, e.g. [2]. While it has already been shown that a similar concept can be used to correct for motion induced shim changes ([3]), it has become evident recently that projection based shimming is very prone to errors due to cross talk from inhomogeneities along the different axis. We here present the first in vivo results from a more robust projection based real time shim method, which is capable of estimating the magnetisation dependent cross talk of linear inhomogeneities along the two in-plane axis. The benefit of the method is shown in motion corrected ([4]) EPI images.

Methods: To our knowledge cross talk between axes has so far been ignored in projection based shimming. The problem becomes evident when picturing a homogeneous phantom that is shifted outside the iso-centre (Figure 1): an inhomogeneity along one axis will certainly cause effects on the other. For more complex magnetisation distributions, or due to localised coil sensitivities, the cross talk can be much more unpredictable. We here present the first in vivo results from measurements where the cross talk is estimated and then taken into account in real-time on the scanner and fed back to the sequence for a correction of the trajectory.

Instead of acquiring projections at different time points after the excitation, as suggested by [2] and [3], we here calculate phase differences relative to a reference projection, acquired at the beginning of the measurement. We assume the linear inhomogeneities to be small enough to consider the cross talk between the axes to be linear, so that they can be calibrated for during the first repetitions of the measurement; this calibration is then used in a magnitude weighted fit of the phase difference of the reference and later projections.

We performed two measurements in a healthy volunteer on a 3T TIM Trio (Siemens Healthcare, Erlangen, Germany). During the first one we calculated and corrected for the shim changes in real time, in the second the values were only calculated but not corrected for. In order to estimate the cross talk we applied gradient moments of one axis on the respective other axis during the first two TRs. The subject was asked to hold his breath during the calibration, in order to avoid inconsistencies. From the third TR on the relative shim changes were measured. The imaging parameters were: FOV 0.224mx0.224m, 96x96 matrix, 6/8 partial Fourier, 13 slices, TE=27ms. A TR of 1s was chosen, leading to a breath hold time of about 5s, including a default 3s dummy scan period of the sequence to reach the steady state. Due to the feedback mechanism into the sequence a delay of 3ms needed to be inserted in addition to the projection acquisitions, resulting in a minimum TE of 27ms. Every 20s the subject was asked to perform in both measurements the same head rotations: 1) centre, 2) up, 3) centre, 4) down, 5) centre, 6) up, 7) centre and 8) down. The subject did not know about the difference of the two measurements. The PACE method suggested by Thesen et al. [4] was used for motion correction.

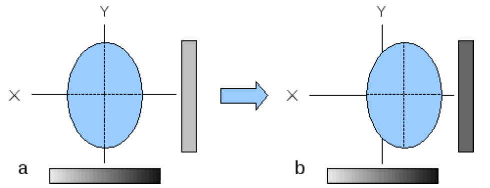

Figure 1: Effect of the position of an object and present inhomogeneities on the inhomogeneities seen by projections. Here an inhomogeneity along X would lead to an apparent offset on Y.

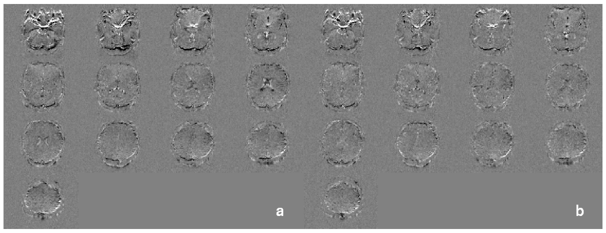

Figure 2: a) The differences of head position 2) and 4) (up-down, see text) and b) differences of position 6) and 8) (again up-down), using the suggested real-time correction (measurement one). The comparison shows that the results are reproducible.

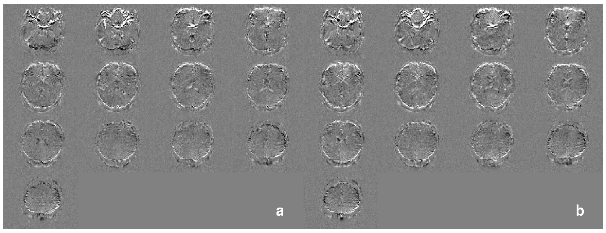

Figure 3: the same differences as for Figure 2, taken from the second measurement, where no correction was performed. The same scaling was used as in Figure 2.

Results & Discussion: Figure 1a shows the differences of head rotations 2) and 4) (up-down, a). To demonstrate the stability of the method the differences of the same head rotations at a later time point (6) - 8)) are given in (b). Some residual differences can be observed but overall the differences are much smaller than in Figure 3, where the corrections where discarded. The main improvement can be observed in central slices, whereas in the lower areas the method seems to overcompensate slightly and thus leads to overall reduced but locally increased distortions.

To our knowledge we have here presented the first in vivo measurements of projection based real time shimming that is capable of measuring and taking into account not only the slope of phase differences, but the associated cross talks as well. It was demonstrated that the residual differences that can be observed in motion corrected images can strongly be reduced by the consistent linear real time shimming.

References: [1] Zaitsev et al., MRM 52, 1156-1166, 2004; [2] Ward et al. MRM 48, 771-780, 2002; [3] Splitthoff et al., HBM, Melbourne, 2008, #1295; [4] Thesen et al., MRM 44, 457-465, 200.

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