Direct and Independent Estimation of B_0 Components based on Raw EPI Data

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Introduction: Gradient Recalled Echo Planar Imaging (GRE-EPI) is sensitive to spatial and temporal changes of B_0 arising from susceptibility effects, temperature changes of the shims and motion of the subject. This leads to time variation of image artifacts such as distortions and intensity losses. Commonly, distortion correction is performed based on a calibration scan preceding the actual measurements so temporal changes of B_0 can not be taken into account. A possible remedy is the extraction of field gradients from EPI raw data as published [1, 2, 3] (method A, B and C respectively). For all three methods, the gradient maps in readout direction (Gx) are however dependent on the gradient maps in phase encoding direction (Gy). Here a novel filter scheme to estimate Gx-maps independently from Gy-maps is presented. The gradient maps calculated with the method introduced here are compared with A, B and C in in-vivo experiments.

$$\mathcal{J}_f(\vec{r}, p_{k_y}) = \mathcal{FT}^{-1}\left\{S(\vec{k})\right\} \otimes \mathcal{FT}^{-1}\left\{f(\vec{k}, p_{k_y}, p_{k_x}, \sigma_{k_y}, \sigma_{k_x})\right\} \qquad \text{(Eq. 1)}$$

Theory: The k-space filtering concept [3] can be formulated as a convolution between the signal *S* and a sliding filter *f* centered at (p_{kx}, p_{ky}) and with optimized widths σ_x and σ_y. (Eq. 1) can be separated of x and y which allows to perform two filter operations in hybrid spaces. A 2D wave with Gaussian shape is used as filter *f*. The position of the maximum of $\mathcal{J}_f$ (Eq. 1) is proportional to the echo shifts δ_{ky} and δ_{kx} which are calculated for each pixel. The gradient maps are calculated with (Eq. 2). Δ_T is the echo spacing time, t_{TE} the echo time and Δ_{ky} the k-space pixel size. As seen in (Eq. 2) the fraction in Gx is the tangents of the angle Θ in the triangle OPA (Fig. 1 a) which describes the contour line for Gx (see Fig. 1a) in case of a Cartesian trajectory and when the dwell is neglected. In order to have good matching between the sliding filter and the contour lines for Gx estimation, the trajectory of the sliding filter has to match the contour line. This method, referred to as D, is shearing *f* by Θ with fixed point O. Gx-maps can be estimated directly from the angle Θ at which the pixel intensity is maximal (Eq. 1 & 3). Gy-maps are determined in the same manner as in C.

$$G_y = \frac{\delta_{\mathrm{ky}}}{\gamma\left(t_{\mathrm{TE}} + \delta_{\mathrm{ky}}\frac{\Delta_T}{\Delta_{\mathrm{ky}}}\right)}, \qquad G_x = \frac{\delta_{\mathrm{kx}}}{\gamma\left(t_{\mathrm{TE}} + \delta_{\mathrm{ky}}\frac{\Delta_T}{\Delta_{\mathrm{ky}}}\right)} \qquad \text{(Eq. 2)}$$

$$G_x = \frac{\tan(\Theta)}{\gamma} \qquad \text{(Eq. 3)}$$

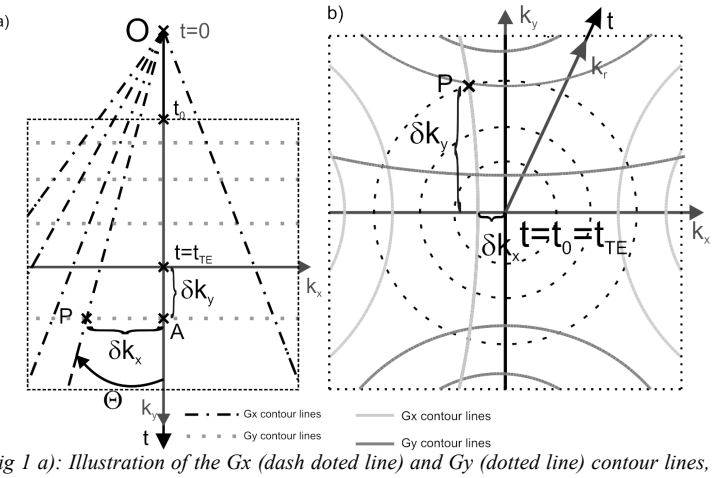

Fig 1 a): Illustration of the Gx (dash doted line) and Gy (dotted line) contour lines, in k_x-t space. t_0 is the time between the RF pulse and the k-space acquisition start. P is the echo and A its projection on the t-(ky) axis. k-space is delimited by a dotted square. b): Illustration of the contour lines for a spiral trajectory. The dotted line is the spiral when the azimuth time can be neglected. Top and bottom are the Gy contour lines and right and left the Gx contour lines.

Methods: One experiment was performed on a 3T Tim TRIO scanner (Siemens Healthcare, Erlangen, Germany). Echo planar (EP), gradient echo image reconstruction and the methods A, B, C and D were implemented in MATLAB (The Mathworks, Natick, AM, USA). B_0 maps of 40 slices from six healthy volunteers were measured with a dual echo GRE sequence (t_{TE1}=3.78ms, t_{TE2}=6.24ms, t_{TR}=345ms, FOV=240×240×2.5mm, matrix size 96×96) and corresponding EP images (t_{TE}=33ms, Δ_T=0.6µs) were acquired. Images were masked and co-registered with FSL[4]. The B_0 maps were used to distort the dual GRE images and simulate distorted field maps B_{D0}. The gradients maps of B_{D0} and from the 4 methods were calculated. The root mean square deviation (RMSD) between the gradient maps from B_{D0} and A, B, C and D was calculated and averaged (aRMSD) over the number of volunteers and slices. Slices with large amount of signal losses resulting in incorrect masking were omitted from averaging.

Results: The results are summarized in Fig. 2. It is visible that the methods D and C have similar and lower aRMSD compared to the methods B and A. In Fig. 3 Gx maps from the A, B, C, D and from B_{D0} are shown. The methods D and C give visually identical Gx maps which are smoother than the maps from A and B.

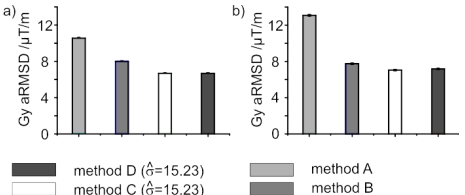

Fig. 2: Comparison of aRMSD for the 4 methods: a) Gy and b) Gx maps. Error bars are plotted.

Conclusion: In this work we show that the proposed filter scheme (D) produce Gx and Gy maps which are more accurate than B and A and equally precise as C. The proposed filter scheme has the advantage of estimating Gx maps independently from Gy values. The presented method is using the contour lines to calculate Gx and Gy. The contour lines are specific for a given k-space trajectory (here Cartesian). For a given trajectory the contour lines have to be derived in order to design an appropriate sliding filter scheme. Fig 1 b) is illustrating the contour lines of Gx in case of a spiral trajectory.

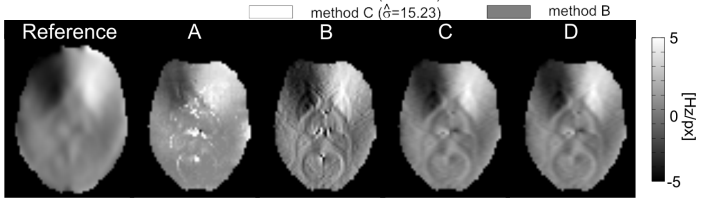

Fig. 3: Reference: Gx map of the distorted field map (smoothed for visualization). Following are the Gx maps from the methods A, B, C and D

Acknowledgments: This work has been supported by the German Research Foundation, grants SP 632/3 – 1 and ZA 422/2 – 1 in part by the INUMAC project supported by the German Federal Ministry of Education and Research, grant #01EQ0605.

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