Correction of Local Image Intensity Dropout Associated with Intravoxel Dephasing in Gradient Echo Imaging Using Local Field Maps

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Introduction: Gradient echo imaging techniques are vulnerable to local signal dropout in regions of high B_0 inhomogeneity due to non-refocussed intravoxel dephasing. These dropouts can complicate the interpretation of gradient echo images, and cause difficulties in intensity-based automated segmentation methods. Here we describe a method for calculating and correcting for these effects, and present preliminary results demonstrating its utility.

Theory: Given an original image $\rho_0(x_0,y_0)$, the signal obtained from gradient echo can be written as:

$$S(k_x,k_y)=\int_{Fov_x} dx_0 \int_{Fov_y} dy_0 \int_{\Delta z} dz\rho_0(x_0,y_0,z)e^{-i2\pi\gamma\Delta B(x_0,y_0,z)TE}e^{-i2\pi k_x(x_0+\frac{\Delta B(x_0,y_0,z)}{G_x})}e^{-i2\pi k_y y_0} \qquad (1)$$

where Fov_x and Fov_y are the field of view in the x and y directions respectively and Δx, Δy and Δz are the voxel sizes. Performing a discrete inverse Fourier transform, the measured image can be written as

$$\rho'(x,y_0)=\int_{\Delta z} dz\rho_0(x,y_0,z)e^{i2\pi\gamma\Delta B(x,y_0,z)TE}*\mathrm{sinc}(\frac{x-x'}{\Delta x})*\mathrm{sinc}(\frac{y'-y_0}{\Delta y}) \qquad (2)$$

where $x=x_0+\frac{\Delta B(x_0,y_0,z)}{G_x}$, and $*$ denotes convolution.

Our method of correction is based on the following two assumptions: 1) the spin density inside the voxel is homogeneous; 2) the field inhomogeneity is locally linear in x, y, and z over a range of a few voxels. Then

$$\rho'(x,y_0)=\rho_0(x,y_0,z_0)\int_{\Delta z} dze^{i2\pi\gamma\Delta B(x,y_0,z)TE}*\mathrm{sinc}(\frac{x-x'}{\Delta x})*\mathrm{sinc}(\frac{y'-y_0}{\Delta y}) \qquad (3)$$

We can define a dephasing factor

$$P(x,y_0,z_0)=\int_{\Delta z} dze^{i2\pi\gamma\Delta B(x,y_0,z)TE}*\mathrm{sinc}(\frac{x'-x}{\Delta x})*\mathrm{sinc}(\frac{y'-y_0}{\Delta y}) \qquad (4)$$

such that $\rho'(x,y_0)=\rho_0(x,y_0,z_0)P(x,y_0,z_0)$ (5)

Calculation of the dephasing factor $P(x,y_0,z_0)$ from the local field map then allows us to recover the local signal loss.

$$\rho_0(x,y_0,z_0)=\frac{\rho'(x,y_0)}{P(x,y_0,z_0)} \qquad (6)$$

Using field maps obtained for the imaging slice and the adjacent slices, we can calculate the field at any point inside each voxel using assumption 2. We can also relax assumption 2 and calculate the field by expanding it to higher order.

Methods: The method was tested on a Philips 3T Achieva scanner, using a phantom consisting of a mineral oil filled bottle (22cm long with diameter 13cm) with a metal staple (3mm long) anchored to the bottom. 2D multi slice gradient echo images were acquired to map the field, with FOV = 20 cm, slice thickness = 4mm, 9 slices, zero gap, TE = 13, 14, 15 msec, TR = 300 msec, matrix size = 256x256.

Results: Fig. 1a-c show the field maps obtained from contiguous slices close to the B_0 perturber. Fig. 1d shows the raw image $\rho'(x,y_0)$ from the center slice (Fig. 1b), while Fig. 1e shows the corresponding map of the dephasing factor P for that slice calculated from the local field map assuming only 1st order (linear) estimates of the intravoxel field gradients. Finally, Fig. 1e shows the intensity corrected image of the same slice. Fig. 2 compares the image profiles across the central line of the corrected and uncorrected images.

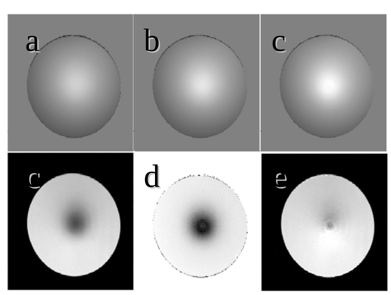

Fig. 1

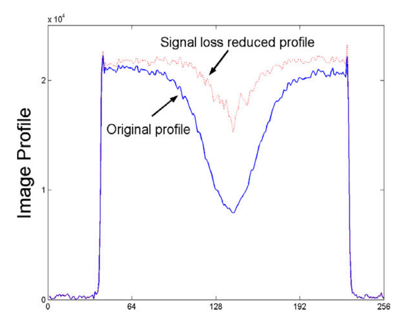

Fig. 2

Discussion: We have introduced a strategy for correcting the signal dropout associated with B_0 inhomogeneity by assuming: 1) the spin density inside the voxel is homogeneous; and 2) the field inhomogeneity is locally linear. Assumption 2 is not a strict condition as we can expand the field to 2nd or higher order locally using the field map. This method may also be used to correct the intensity distortion in gradient echo EPI, either before or after correcting the geometrical distortion. The effectiveness of this method depends on the accuracy of the field map. Finally we note that this approach does not improve the local image SNR, as it corrects for intravoxel dephasing by local scaling of both the signal and the noise. Its performance thus will be limited by local SNR.