Non-Fourier Reconstruction Can Prevent Image Dropouts

R. W. Cox[1], L. A. McCall[2]

[1]National Institute of Mental Health, Bethesda, MD, United States, [2]Dept of Physics, Auburn University, Auburn, Alabama, United States

Introduction:

Uncompensated through-slice magnetic field gradients cause extensive signal dropouts in full *k*-space rectangular-scan EPI due to the long interval before TE is reached. Techniques to fix this problem include *z*-shimming [1-2] and tailored RF pulses to alter the phase profile through the slice [3]. Herein, we propose another method, which in its simplest form does not need a modified EPI pulse sequence or any time penalty, just a new reconstruction algorithm. This method can also be used in conjunction with other techniques, since it only requires a magnetic field map and new software.

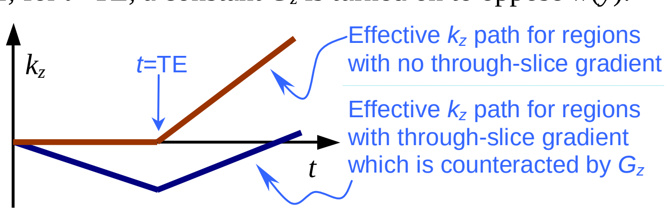
The Signal-Magnetization Relationship and non-Fourier Reconstruction:

The basic problem is that the relationship between the measured signal and the magnetization is no longer precisely the Fourier transform. If we abstract out the x - k_x direction as being acquired too rapidly for dephasing to matter, then the signal at time t after excitation can be modeled as $S(t) \propto \int_{-\text{FOV}/2}^{\text{FOV}/2} \int_{-h/2}^{h/2} M(y,z) e^{-ik_y(t)y} e^{-i[w(y)t + k_z(t)]z} \; e^{-R_2^*(y,z)t} dz\, dy$, where $M(y,z)$ is the post-RF transverse magnetization density (at $t=0$), FOV is the field-of-view (in the *y*-direction), *h* is the slice thickness, $k_y(t)$ is the phase-encoding readout, $k_z(t)$ is the integral of any *z*-shimming gradients, and $w(y)$ is γ times the spatially-dependent through-slice magnetic field gradient. Idealizing further that the magnetization profile in the *z*-direction is rectangular, the signal model becomes $S(t) \propto \int_{-\text{FOV}/2}^{\text{FOV}/2} M(y) e^{-R_2^*(y)t} e^{-ik_y(t)y} \operatorname{sinc}\left[\frac{h}{2}\left(w(y)t + k_z(t)\right)\right] dy$, where $\operatorname{sinc}(x) \equiv \sin(x)/x$. If $w(y)=0=k_z(t)$, then this model is the usual Fourier relation between $S(t)$ and $M(y)$. When $k_z(t)\equiv 0$, at locations *y* where $w(y)h \gtrapprox 2\pi/\text{TE}$, the dephasing is such that $\operatorname{sinc}\left[\frac{h}{2} w(y)\text{TE}\right] \approx 0$ and virtually no signal is received from such values of *y* in the vicinity of t=TE; normal Fourier reconstruction results in nearly total signal dropout in these locations. However, if the readout starts soon enough after excitation, the early part of the data ***will*** contain some signal from the dropout locations at nonzero values of k_y (while $w(y)ht \lessapprox 1.5\pi$, say). The non-Fourier reconstruction model we propose is thus to write the model for the image $I(y)$ as $S(t) \propto \int_{-\text{FOV}/2}^{\text{FOV}/2} I(y) e^{-ik_y(t)y} \operatorname{sinc}\left[\frac{h}{2}\left(w(y)t + k_z(t)\right)\right] dy$, and then invert this linear integral equation numerically to solve for $I(y)$; solving this equation requires having a B_z field map, so that $w(y)$ is known. The discretization is $S_m = \sum_n e^{-ik_y(t_m)y_n} \operatorname{sinc}\left[\frac{h}{2}\left(w(y_n)t_m + k_z(t_m)\right)\right] \cdot I_n$, where *n* is the spatial index and *m* is the temporal index. This is a system of linear equations for the image vector $[I_n]$ given the data vector $[S_m]$, and can be solved using the singular value decomposition (among many possible methods). As mentioned above, the speed of acquisition in the k_x direction means that normal FFT reconstruction can be used for the x - k_x inversion; therefore, although the matrix is dense, it can be solved quickly since it will involve (typically) only 64-128 unknown values. Once the subject- and orientation-specific gradient field map $w(x,y) = \gamma \partial B_z(x,y,z)/\partial z\big|_{z=0}$ is available, the SVD for each slice and each *x* can be precomputed, and the overall reconstruction speed for a long imaging run of EPI data will be very fast.

Preliminary Results and Discussion:

Simulated data were generated that correspond to a realistic EPI acquisition: 27 ms readout window starting at 6 ms after the center of the slice excitation RF; 64 data points in k_y with a 240 mm FOV; localized 100 Hz through-slice frequency change. The results show that knowing $w(y)$ to within 10% provides an accurate image reconstruction.

Using a nonzero compensating $k_z(t)$ for the second half of the acquisition provides a way to gain a second partial acquisition of data from "bad" regions. We keep G_z=0 until *t*=TE; for *t*>TE, a constant G_z is turned on to oppose $w(y)$. Simulations show that this type of compensation, coupled with non-Fourier reconstruction, is less sensitive to errors in the estimated $w(y)$ and to noise. Further work is planned to estimate the sensitivity to R_2^* changes and global field offsets, determine the PSF, choose the $k_z(t)$ compensation path optimally, &c.



References:

[1] Glover GH, *MRM* **42**: 290-299, 1999. **[2]** Song AW, *MRM* **46**: 407-411, 2001. **[3]** Pipe JG, *MRM* **33**: 24-33, 1995.