A Simple Approach to Measure and Correct for B0 and Linear Eddy Currents

A. Lu[1], B. L. Daniel[1], K. B. Pauly[1]
[1]Department of Radiology, Stanford University, Stanford, CA, United States

INTRODUCTION

Eddy currents can introduce artifacts in MR images or distort slice profile during spectral-spatial excitation. B0 eddy currents and linear eddy currents behave differently and therefore require separate compensation. However, characterization of both terms may be time-consuming and/ or require special experiment setup [1]. Duyn [2] has proposed a simple method to measure the k-space trajectory, and Gurney has extended this method to measure the B0 eddy current [3]. In this work, we present an improved approach to extract the B0 and linear eddy current terms simultaneously. Our phantom studies with a multiple-echo projection reconstruction (PR) [4] sequence demonstrate significantly improved image quality with the correction of both terms.

MATERIALS AND METHODS

The proposed method using linear least square fitting to extract eddy current terms from signal phases measured using Duyn's method. On a given axis, eddy current correction data are acquired with the testing gradient at a series of amplitudes and from a set of off-isocenter slices. Assuming B0 eddy currents vary linearly with gradient amplitude but are independent of spatial location, while linear eddy currents linearly depend on both gradient amplitude and location, and ignoring high order eddy currents, the phase ($\varphi(x,g,t)$) obtained with gradient amplitude $\boldsymbol{g}$ for a slice at location $\boldsymbol{x}$ can be modeled as:

$$\varphi(x,g,t) = \hat{k}(t)gx + \hat{\phi}_{B0}(t)g + \phi(t) = (\hat{k}(t)x + \hat{\phi}_{B0}(t))g + \phi(t)$$

where $\hat{k}(t)$ corresponds to the k-space trajectory created by the applied gradient and linear eddy currents and $\hat{\phi}_{B0}(t)$ phases due to B0 eddy currents, both with the applied gradient at unit amplitude. $\phi(t)$ is the phase from all other sources such as B0 inhomogeneity that is independent of applied gradient. At each sampling point, signal phases from the same slices are linearly fit with respect to $\boldsymbol{g}$. The linear coefficients give $\hat{k}(t)x+\hat{\phi}_{B0}(t)$, which is then linearly fit with respect to $\boldsymbol{x}$ to extract $\hat{\phi}_{B0}(t)$ and $\hat{k}(t)$. Alternatively, we can also first fit the phase to $\boldsymbol{x}$, and then fit the resultant coefficients with respect to $\boldsymbol{g}$.

To correct for the eddy currents induced by the readout gradient, the measured $\hat{k}(t)$ is scaled by gradient amplitude to calculate each k-space trajectory, which is then used for reconstruction. This corrects for the linear eddy currents. B0 eddy currents are corrected using $\hat{\phi}_{B0}(t)$ by correcting the phase of the signal on a per data point basis.

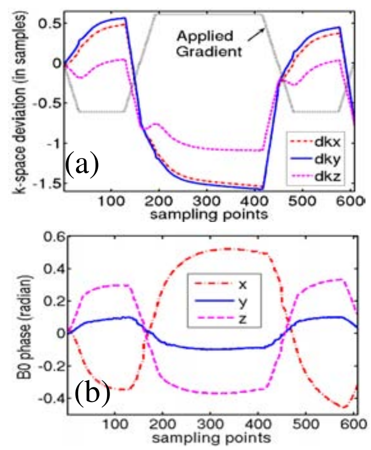

Figure 1. a) Measured k-space deviation due to linear eddy currents of the applied gradient (arrow) b) Phase accumulated by B0 eddy currents

RESULTS AND DISCUSSION

Experiments were performed on a 0.5T GE Signa open scanner. A four-echo 2D PR readout is used for imaging as shown in Figure 1a (arrow). The corresponding B0 and linear eddy currents measured on all three axes are shown in Figure 1a and b, respectively. Both eddy currents indicate larger distortion during the late echoes. As shown in Figure 2a, image reconstructed from the fourth echo shows significant distortion. With linear eddy current correction, reasonable image quality is obtained in Figure 2b. Further B0 eddy current correction results in a much sharper and more uniform image ((Figure 2c). The effectiveness of the correction is demonstrated again in the knee images (arrows), which are reconstructed using all four echoes without eddy current correction (Fig. 2d), with linear eddy current correction (Fig. 2e) and with both correction (Fig. 2f). Though eddy currents induced artifacts is less noticeable due to echo combination, increasing improvement in image sharpness is observed (arrows). Fat signal is suppressed to a great extent also owning to echo combination.

Theoretically, only four acquisitions are needed on each axis for the linear fitting processes (2 slices, each sampled with two gradient amplitudes). In practice, more number of slices and gradient amplitudes are preferred to improve the robustness of the fitting processes. This can be achieved without much time penalty by replacing signal averages that usually needed in order to improve SNR with Duyn's approach. Higher order polynomial fitting is also possible with this approach, and similar results have been obtained for the B0 term and linear gradient term using a 2nd order polynomial fit.

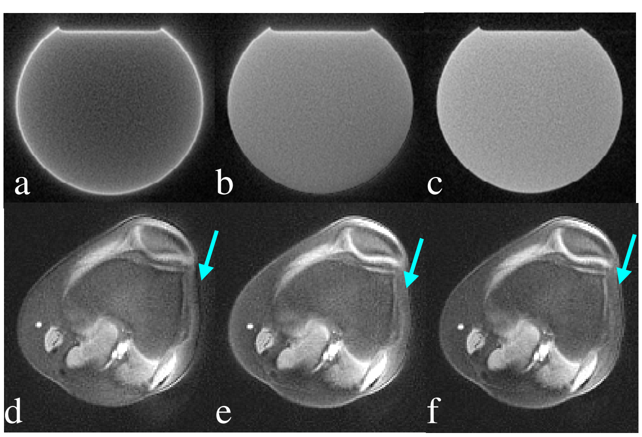

Figure 2. Images show effectiveness of eddy correction. (a, d) without correction. (b,e) with linear eddy current correction (c,f)) with both linear and B0 eddy current correction.

CONCLUSIONS

A simple method to measure and correct for both B0 and linear eddy currents are presented. Our phantom study has shown significant improvement in image quality when these are used for correction during reconstruction. The measured B0 terms and linear gradient terms can also be used to prospectively compensate the RF pulse and the selective gradient to improve spatial excitation.

REFERENCE

1. Beinstein et al., "Handbook of MRI pulse sequence", Elsevier academic press, 2004.
2. Duyn et al., JMRI, 132 150 (1998)
3. Gurney et al., Proc. 13rd ISMRM, 866 (2005)
4. Lu et al., MRM 53: 692-699 (2005)

ACKNOWLEDGEMENT: NIH CA092061, P41 RR009784