B0 Field Mapping with a Fast Asymmetric Spin Echo Sequence at High Field

Y. Zhao[1,2], H. Zeng[2], J. C. Gore[2]

[1]Department of Electrical Engineering, Yale University, New Haven, CT, United States, [2]Vanderbilt University Institute of Imaging Scienece, Nashville, TN, United States

Introduction

Measuring the spatial variation of the static magnetic field (B_0 Field Mapping) is essential for automatic shimming. It is also necessary for many image reconstruction methods that attempt to correct B_0 inhomogeneity-induced geometric distortions and/or signal losses. With increasing use of high field imaging, the conventional field mapping method [1], which calculates the phase differences between two gradient-echo images collected at different echo times (TE), becomes unreliable becuase B_0 inhomogeneities at high field can cause signal dropouts and geometric distortions in gradient echo images. We have developed and implemented a fast B_0 field mapping method based on an asymmetric fast spin echo sequence. This method not only makes accurate B_0 measurement possible in regions with large field inhomogeneities, such as tissue/air boundaries, but also reduces the acquisition time compared to the conventional method.

Method

FASE also acquires two images to reconstruct B_0. The first image ρ_1 is an ordinary multi-shot FSE image. The second image ρ_2 is acquired with the same sequence but with acquisition windows and readout gradients delayed by Δt, making ρ_2 an asymmetric spin echo image. The phase difference ($\Delta\Phi$) between these two images is due to T_2* decay caused by magnetic field inhomogeneity: $\Delta B=\Delta\Phi/\Delta t$. Usually Δt is set to be less than 4 ms, small enough to not cause any phase wraps in $\Delta\Phi$. If the field to be measured is highly inhomogeneous, phase wraps in $\Delta\Phi$ can be removed using a "quality-guided" 2D phase unwrapping algorithm [2].

For an infinitely thin slice $\rho(x,y)$ acquired with a gradient echo sequence, if relaxation is ignored, the received signal can be expressed as

$$S = \iint \rho(x,y) e^{-i2\pi\Delta B(x,y)TE} e^{-i2\pi k_x (x+\frac{\Delta B(x,y)}{G_x})} e^{-i2\pi k_y y} dxdy$$

where TE is the echo time, $\Delta B(x,y)$ is the field inhomogeneity and G_X is the readout gradient. The phase term $\exp(-i2\pi\Delta B(x,y)TE)$ introduces signal losses in the gradient echo images and make it impossible or difficult to measure regions with large $\Delta B(x,y)$. This term also makes the field map a function of echo time. Choosing different TE_1 and TE_2 will result in a different measurement. The π pulses rephase the spins in FSE, so there are no such phase terms in the FASE signal. Field mapping using FASE is therefore less affected by signal losses and is independent of echo time.

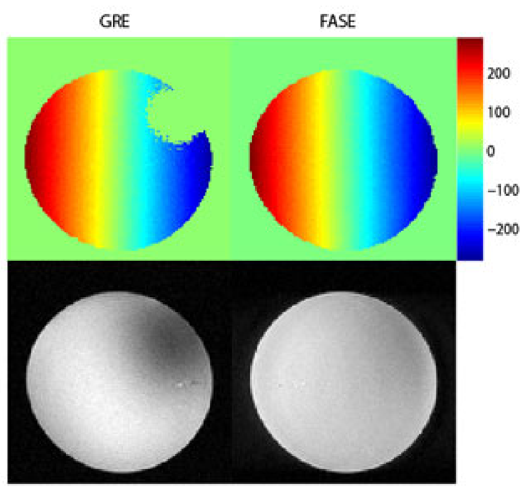

Fig.1 Field map (top row) and images (bottom row) acquired with gradient echo (left column, TR = 500 ms, TE_1/TE_2 = 12/15 ms) and fast asymmetric spin echo (right column, TR=2000 ms, ETL=16, Δt = 3ms) at 7T. Image Matrix 128x128; FOV 38 mm. Field map is in Hz.

Experiment

A 30mm diameter cylindrical tube filled with water was used as a phantom to test the effectiveness of FASE on a Varian INOVA 7T system. A 2 mm section of a paper clip was attached on the surface of the tube to distort B_0 and introduce susceptibility artifacts in the images. Two field maps were first acquired under the "well-shimmed" condition by the gradient echo method and the FASE method respectively. The echo time difference in the GRE method was the same as the Δt in FASE. The X shim (gradient X) was changed and the field was measured again with the two methods. The field difference between these two shimming conditions should show a linearly distributed gradient field X.

Results and Discussions

The GRE method took 128 seconds to obtain a 128x128 field map with TR = 500 ms. For FASE, the time was only 32 seconds when TR is 2000 ms and echo train length (ETL) is 16. The field map is reasonably accurate with TR = 1000 ms and ETL = 32 when the total acquisition time is only 8 seconds.

Field maps obtained with GRE and FASE at 7 T are shown in the top row of Fig.1. The bottom row shows the corresponding gradient echo image (TE_2) and the FASE image. The signal loss in the GRE image makes it impossible to measure the B_0 distribution in the upper right area. Under the same field conditions, FASE peforms very well. With increasing B_0 inhomogeneity (such as the B_0 field near the paper clip), the GRE field map starts to show geometric distortions along the readout direction. Inconsistencies were also found in the GRE method when using different sets of echo times.

FASE is easy to implement. One concern is that shifting readout gradients and acquisition windows by Δt will increase the echo spacing, which will aggravate blurring and ringing artifacts along the phase encoding directions. To alleviate this artifact, a modified FSE sequence has been developed to remove the side lobes of the point-spread-function by varying the first effective TE of different excitations [3].

Conclusions

Field mapping using fast asymmetric spin echo is a feasible technique to reconstruct the B0 field in a faster and more accurate way than conventional gradient echo methods. It should be very useful for automatic shimming and high-fidelity image reconstruction at high field.

References

1. Schneider E, Glover G. Rapid in vivo proton shimming. Magn Reson Med 1991; 18: 335-347
2. Ghiglia DC, Pritt MD, Two-Dimensional Phase Unwrapping. New York: Wiley, 1998.
3. Zeng H et al. A modified multi-shot Fast Spin Echo pulse sequence to reduce blurring.