Automatic Z-shimming Based on A Real-time Feedback Optimization Framework in BOLD-EPI

Y-W. Tang[1], and T-Y. Huang[1]

[1]Department of Electrical Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan

Introduction

Z-shimming has been shown a practical to compensate through-slice spin dephasing in BOLD-EPI [1-2] by the modulation the offset of gradient moment (ΔMz) in the slice selection direction. The optimized z-shim gradient is generally estimated from a set of EPI-images acquired with z-gradient stepping. This "global search method" steps through a range with discrete ΔMz values. Therefore, the precision of the optimized ΔMz is limited by the step size. Furthermore, the stepping scan and the off-line post-processing generally takes minutes to accomplish. In this study, we proposed a novel real-time feedback optimization framework to solve this problem.

Materials and Methods

To optimize theΔMz, we implemented a feedback loop between the scanner (HOST) and the image processing computer (PC) through the network connection. The real-time scanner control was accomplished by a configuration file. Before the EPI scan, HOST read the ΔMz stored in this file and recorded this value in a log file (Z-LOG). Then, the EPI scan was performed with the gradient strength adjusted according to the ΔMz. Right after EPI scan of each repetition, the reconstructed images were sent to PC in real-time. A MATLAB program detected the new incoming images and then estimated the optimized ΔMz by Brent's method [3] based on the second order polynomial fitting. Then, PC changed the configuration file of ΔMz for the next EPI scan with the newly calculated ΔMz. After repeating the feedback loop, the optimized ΔMz can be obtained at the end of the iteration. Moreover, to prevent the possible signal delay (network problem or long computation time) spoil the feedback loop, the MATLAB program checked the Z-LOG file before running Brent's algorithm. If the ΔMz stored in the Z-LOG file did not matched the previous result of Brent method, the following optimization step was skipped.

The optimization procedure was separated into three steps. First, the cost function of Brent's optimization method was the summation of the pixel intensities in the EPI images. This step kept finding ΔMz until the convergence condition was reached. The image acquired with the converged ΔMz was considered as a reference image. Subsequently, two other z-shim offsets for signal compensation of the reference image were searched with positive and negative ΔMz individually. The cost function of the second and third steps was the summation of the pixel intensities of the MIP image obtained by calculating the maximum-intensity projection of the reference image and the newly obtained EPI images.

Our framework was implemented with a Siemens 3T Tim-Trio system and a personal computer (CPU: Pentium 3.0 GHz, RAM: 2G). The scan parameters of feedback-controlled EPI were (TR/TE: 1000/40 *ms*, matrix: 64×64, FOV: 200×200 *mm*).For the volunteer study, three subjects underwent participated the experiment. For comparison, sweep scans (ΔMz: -3000 to 3000 $\mu T / m \cdot ms$, step size: 100 $\mu T / m \cdot ms$) were also performed.

Results

Figure 1 shows the pixel-intensity-summation of the images obtained by the sweep scan (blue circle) and the proposed feedback optimization method (red diamond) in the volunteer study. Notice that the best ΔMz found by our method matched with the global search method. Furthermore, our method reached the convergence quickly (iteration: 9 times) whereas sixty images had to be acquired for the conventional global search method.

Fig.2 shows the reference images, z-shim images, and MIP images obtained from a healthy volunteer. Each MIP image is consisted of three images, including a reference image and two z-shim images corresponded to positive and negative z-shim direction separately. The susceptibility-induced signal loss can be mostly compensated from the positive z-shim image with high intensity near air/tissue interfaces.

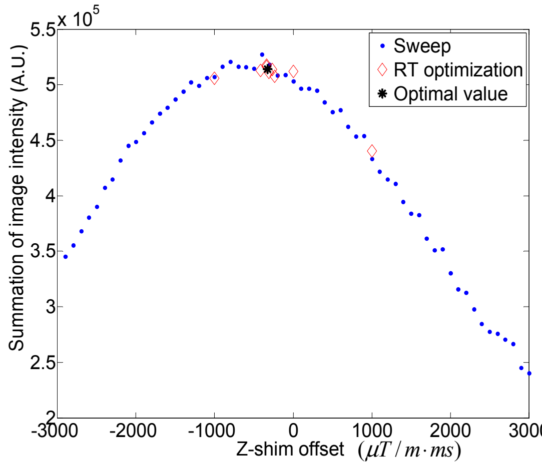

Fig. 1 The comparison of real time optimization and traditional z-shimming sweep. Each spot means the intensity summation of z-shim image. The black star symbol indicates the converged value of red diamonds, and that is near the peak of sweep profile. The real time optimization totally acquires 16 images but only 9 z-shim values are calculated. The proper ΔMz calculated by our method is -327 $\mu T / m \cdot ms$ and the best ΔMz in global search is -400 $\mu T / m \cdot ms$.

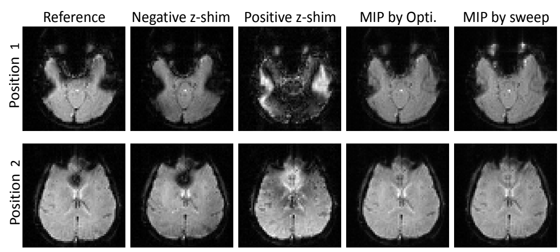

Fig. 2 The three z-shim images evaluated by real time optimization are combined into a MIP image showed in the 4th column. The MIP image consisted of three z-shim images by traditional z-shimming method is showed in the 5th column.

Discussion and Conclusions

In our study, a real-time feedback optimization approach was proposed to seek the best ΔMz quickly and automatically. We used second-order Brent's method for the optimization since the curve (ΔMz versus signal intensity) was generally a smooth function. The feedback loop was built by network connection and real-time image processing. Although the feedback procedure generally took less than a second, this method could not work properly when the feedback signal was not sent prior the next EPI scan. Since the each EPI scan should have consistent T1 recovery period, the scan cannot be halt to wait the feedback data. Therefore, to avoid this problem, we introduced a Z-LOG approach to check the consistency of ΔMz values. In our experiments, the convergence conditions were generally reached with less than ten iterations. That is, if no delayed feedback occurs during the iteration, all the three ΔMz values can be obtained in less than thirty repetitions. After the iteration loops, the EPI sequence can continue scanning with the optimized ΔMz. The whole procedure can be done automatically and thus we believe it can be useful for the susceptibility-related studies (e.g. fMRI or brain perfusion)

In conclusion, we accomplished a framework that combines the real time feedback and the optimization algorithm. This method provides fast procedure to obtain accurate parameters for z-shim EPI sequence.

Reference

[1] Frahm, J et al, Magn. Reson. Med(1988), 474-480 [2] Helen Marshall et al, Magn Reson Mter Phy(2009), 22:187-200 [3] W.H. Press, B.P. et al, Numerical Recipes in C(1992)