Fast G-factor Estimation in Multi-band Acquisition Based on Sum of Inverse Distance Model

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INTRODUCTION Inter-slice shift is one of the most important factors affecting the g-factor in multi-band (MB) simultaneous multi-slice acquisition. Previous study[1] has shown that the optimal distance of slice shift can deviate away from intuitive choices such as FOV/N_{slice}. However, optimizing shift pattern is time-consuming because iterative algorithms have to be used. In this study, we propose a fast g-factor estimation model that can approximately output g-factor profile versus slice shift distance using closed form formula, with input of slice number and one parameter quantifying the coil sensitivity in slice direction.

THEORY Considering a 1D MB SENSE reconstruction problem with unit FOV: two pixels from two slices are aliased and two opposite coils are used with sine/cosine sensitivity profiles in x-y plane (Fig. 1). If these two coils have no sensitivity variance along z and the slice shift is *d*, then the SENSE encoding matrix for location *x* is $C = \begin{bmatrix} \sin(\frac{\pi}{2}x) & \sin(\frac{\pi}{2}(x+d)) \\ \cos(\frac{\pi}{2}x) & \cos(\frac{\pi}{2}(x+d)) \end{bmatrix}$

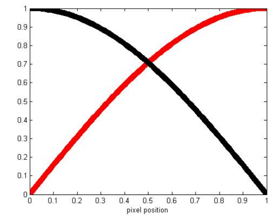

Fig. 1 Idealized sensitivity profiles of two opposite coils for 1D MB problem of two slices. Red for coil 1; Black for coil 2.

The noise amplification (g-factor) on the pixel ρ can be quantified as $g_\rho = \sqrt{(C^H C)^{-1}_{p,p}(C^H C)_{p,p}}$. In this case, g-factors are the same for two pixels regardless of location *x*. This g-factor can be proven close to 1/*d*, for 0<*d*<0.5. For 2D two slices MB problem, mean g-factor can also be approximated by 1/*d*, because the main contribution to slice unwrapping still comes from the pair of opposite coils along phase encoding direction. To extend this model to more than two slices, we can assume that the total noise amplification is the sum of noise amplification between each pair of two slices. For most 8-channel and 16-channel coils, the coil sensitivity variance along z direction is much smaller than that in x-y plane, however, this additional sensitivity encoding information should also be taken into consideration by correcting the distance between slices to be $\sqrt{D^2_{in-plane} + \lambda D^2_z}$, where $D_{in\text{-}plane}$ is the slice shift before correction, λ is the ratio of coil sensitivity variance along z direction to sensitivity variance along x-y plane, and D_z is the slice gap. Therefore, given slice number N and λ, the mean g-factor of MB SENSE can be estimated by

$$g(N,\lambda) \cong \sum_{1 \le i \ne j \le N} \frac{1}{\sqrt{D(i,j)^2_{in-plane} + \lambda D(i,j)^2_z}}$$

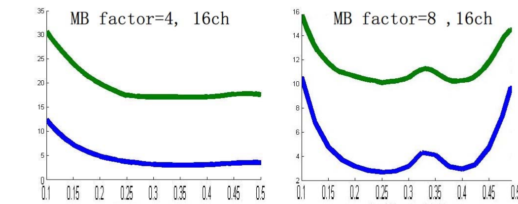

Fig. 2 Mean g-factor versus slice shift (0.1-0.5 FOV) with 16-channel coil. The greens curves are predicted g-factor by model and the blue curves are true g-factor curves measured from coil sensitivity. The curves have been scaled for comparison.

METHODS MB simulations were conducted using 8-channel head coil and 16 channel abdominal coil data. The predicted and true curves of mean g-factor versus slice shift were calculated, with MB factor=4 for 8-channel coil and MB factor=4 and 8 for 16-channel coil. The parameter λ was measured by dividing sensitivity change rate along z direction by sensitivity change rate along x-y plane. Images with slice shifts = 0.25 FOV, 0.33 FOV, 0.4 FOV and 0.5 FOV were reconstructed using SENSE to validate the g-factor curve for 8-channel coil and MB factor=4.

RESULTS As shown in Fig. 2, the predicted g-factor curves after scaling were similar to the true ones. The variation trend and positions of local maxima and minima were well approximated. For 8-channel coil, the g-factor was very sensitive to slice shift, showing large peaks, while for 16-channel coil, the curves was relatively smooth in a wide range of slice shift, with peak at around FOV/3 for both MB factor=4 and 8. Reconstructed images and error maps showed that the reconstruction quality had the same trend as predicted by the model (Fig. 3).

DISCUSSION AND CONCLUSION We proposed a simple model to approximately evaluate the g-factor profile versus slice shift distance, with slices number and one coil sensitivity parameter as input. Using this model, we can quickly optimize the slice shift pattern for MB acquisition. Moreover, the model indicates that some frequently used slice shifts may lead to an undesirable g-factor peak. For example, for some 16-channel coils, we should avoid FOV/3 shift when MB factor=4 or 8.

When increasing distance between adjacent slices, the distance between non-adjacent slices usually becomes smaller. This interaction can explain the fluctuation in g-factor curves. As indicated by the curve of 16 channel coil, there is a low g-factor region around 0.4 FOV. This may related to golden ratio 0.618 as (1-0.618) ≈0.4. With 0.4 FOV shift, we create relatively large distance between adjacent slices while maintaining acceptable distance between non-adjacent slices, similar to the principle of golden angle used in radial imaging[2]. One the other hand, because 8-channel coil has little z direction sensitivity variance, a small distance between any two slices will make huge error in reconstruction, so that FOV/N_{slice} is nearly optimal and any shift making large slice overlap should be avoided.

The accuracy of this model may be further improved by adding high order terms and making object-specific adjustment. For example, the adjustment for brain MB imaging can be investigated in future considering the typical brain shape and tissue characteristics.

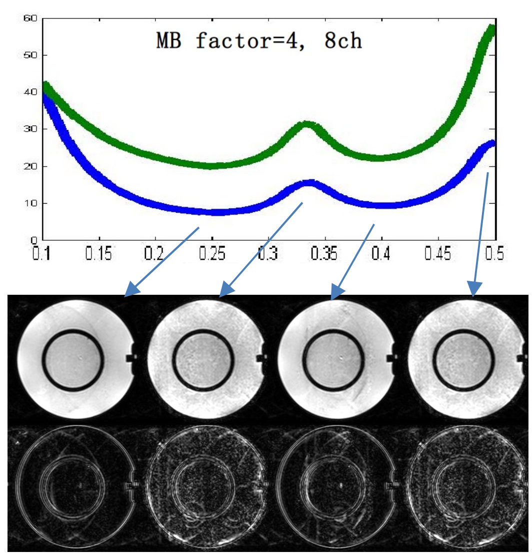

Fig. 3 Mean g-factor versus slice shift (0.1-0.5 FOV) with 8-channel coil and MB factor=4.The greens curves are predicted g-factor by model and the blue curves are true g-factor curves calculated from coil sensitivity. The curves have been scaled for comparison. (b) One slice from reconstructed MB images with the coil and MB factor used in (a) and slice shift = 0.25, 0.33, 0.40 and 0.5 FOV (from left to right) (c) The coresponding reconstruction error maps of (b), with intensity 3× scaling.

REFERENCES

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