Abstract 458

Goodness of fit factor in SENSE reconstruction: a tool for pseudolesion detection and fat unfolding

Session Type: Scientific Session

Topic: Preclinical Studies and Basic Science / Motion, artefacts, quality control

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Purpose / Introduction

Parallel imaging allows in-plane or simultaneous multislice (SMS) accelerated MR acquisitions. However, reconstruction of accelerated datasets is artifact-prone. We describe a method for assessing the consistency of parallel imaging reconstructions and illustrate its application to aid clinical decision in anatomical neonatal brain imaging and fat unfolding in accelerated diffusion weighted imaging (DWI).

Subjects and Methods

Under conjugate gradient (CG) SENSE[1], artifacts can be detected spatially by using the goodness of fit of the reconstruction as given by the χ^2 statistic along channels[2] (see Fig. 1). These maps are useful to aid visual interpretation, help tuning the reconstruction, or trigger further inconsistency correction, such as in the presence of fat.

$$\chi^2(\mathbf{r}) = \|\mathbf{E}^H(\mathbf{ES}(\mathbf{S}^H\mathbf{E}^H\mathbf{ES})^{-1}\mathbf{S}^H\mathbf{E}^H - \mathbf{I}))\mathbf{y}(\mathbf{r})\|_2^2 = \|\mathbf{E}^H(\mathbf{ESx} - \mathbf{y})(\mathbf{r})\|_2^2$$

$\mathbf{r}$	$\longrightarrow$	Spatial position	$\mathbf{S}$	$\longrightarrow$	Sensitivity profile matrix
$\mathbf{E}$	$\longrightarrow$	Fourier encoding matrix	$\mathbf{I}$	$\longrightarrow$	Identity matrix
$\mathbf{y}$	$\longrightarrow$	Measured data	$\mathbf{x}$	$\longrightarrow$	Reconstructed image

Fig. 1. Formulation for the goodness of fit χ^2 in CG SENSE reconstruction. Noise prewhitening is assumed for $\mathbf{y}$ and $\mathbf{S}$. $\mathbf{E}$ may encompass Fourier transform in the phase-encode (PE) direction / spectral undersampling / other modelled phenomena. χ^2 corresponds to the sum over the coils of the squared backprojected reconstruction residuals.

Imperfect fat suppression limits high-B value DWI imaging due to larger reduction of diffused water signal as compared with lipids. Particularly, in accelerated acquisitions, fat can appear distributed over different folded locations. Thus, as a further step in our reconstruction pipeline for SMS EPI DWI[3], SENSE fat unfolding, possible thanks to the water-fat shift[4], is activated for those pixels where the χ^2-factor exceeds a given threshold.

Results

An example of the clinical utility of χ^2-factor maps, which are routinely generated in our neonatal brain imaging reconstructions, is shown in Fig. 2.

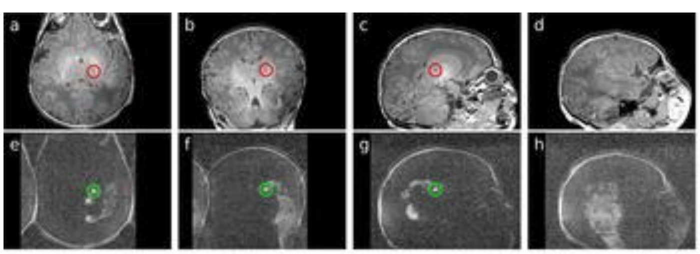

Fig. 2. A potential lesion is enclosed by circles in Figs. 2.a, 2.b, and 2.c. χ^2-factor maps in Figs. 2.e., 2.f., and 2.g. (presented in a logarithmic scale) suggest that the suspected lesion is indeed an artifact. This is further confirmed by sliding to a different sagittal slice (Fig. 2.d), where the χ^2-factor map reveals that the artifact is caused by the baby hand outside the FOV being wrapped inside the brain (Fig. 2.h), particularly at the finger locations.

The fat unfolding method is applied in the reconstruction of the DWI sequence described in Table 1, designed for the developing Human Connectome Project[5]. This is a particularly demanding problem due to aggregated SMS (4x) and in-plane (1.2x) acceleration factors as well as presence of residual ghosting and strong distortions[3], which usually force an enlarged Field of View (FOV) reconstruction. Results are illustrated in Fig. 3. Adequate masking and fat detection maintains acceptable global noise levels (g-factor) while reducing local artifact levels

(χ^2-factor).

Table 1. DWI acquisition parameters. PF: Partial Fourier. TR: Repetition time. TE: Echo time. WFS: Water-fat shift. Four PE with interleaved coverage of the diffusion orientations are acquired for robustness against distortions.

Resolution (mm^3)	Slice distance (mm)	#Coils	PE
1.5x1.5x3	1.5	32	LR/RL/AP/PA
SMS factor	PE shift/Acq. FOV	In-plane factor	PF
4	1/2	1.2	0.86
FOV (mm^3)	TR (ms)	TE (ms)	Flip angle (°)
150x150x97.5	3800	90	90
b-values (mm/s^2)	#Images/b-value	#Images/PE	WFS/Acq. FOV
0/400/1000/2600	20/64/88/128	75	0.356

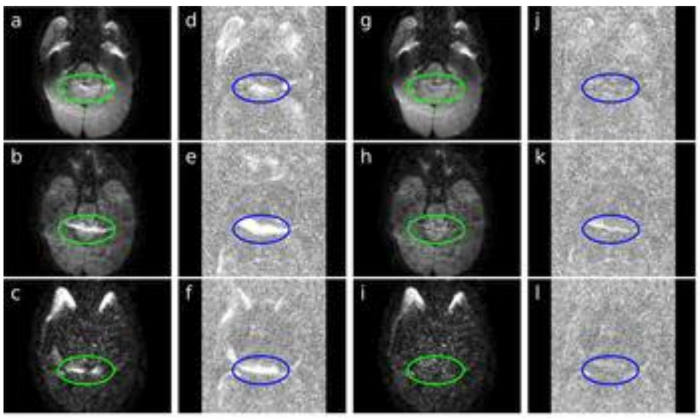

Fig. 3. Fat unfolding in the AP phase encode for $b = 400\,mm/s^2$, $b = 1000\,mm/s^2$ and $b = 2600\,mm/s^2$ (from up to bottom). Figs. 3.a, 3.b, and 3.c show the images before applying the fat unfolding procedure, Figs. 3.d, 3.e, and 3.f show the corresponding χ^2-factor maps (in a logarithmic scale), which appear as sensitive spatial indicators of the presence of fat. The results after applying the unfolding are included in Figs. 3.g, 3.h, and 3.i, where most of the fat signal has been separated from the water with minimum global SNR hit. The χ^2-factor maps after unfolding, in Figs. 3.j, 3.k, and 3.l, show improved consistency and are indicative of residual ghosts.

Discussion / Conclusion

Utility of goodness of fit maps is demonstrated both for visual interpretation of anatomical brain images and fat suppresion in SMS EPI DWI. Due to their versatility, further applications may include improved retrospective motion correction robustness[6] or automated reconstruction parameters selection.

References

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