A POINT SPREAD FUNCTION BASED MEASURE OF ARTEFACT IN PARALLEL MRI RECONSTRUCTION

L. Yang[1], P. Robson[2], and C. McKenzie[1]

[1]Medical Biophysics, University of Western Ontario, London, Ontario, Canada, [2]Department of Radiology, Beth Israel Deaconess Medical Center, Boston, MA, United States

Introduction: The performance of a parallel MRI image reconstruction is generally assessed either by its noise amplification (g-factor) performance or by the amount of residual artefact. Analysis of g-factor is a powerful tool but is necessarily incomplete as it ignores image artefacts [1]. Current measures of artefact, such as artefact power [2,3], are based on some measure of difference in image intensity between a parallel MRI reconstructed image and an artefact free reference image. These metrics are limited because image noise cannot be distinguished from artefact, making it difficult to quantify the trade-off between image reconstruction artefact and noise amplification. A method for calculating the effect of parallel imaging reconstruction on Point Spread Function (PSF) was introduced recently [4]. We propose using a new metric based on PSF as a tool to quantify how much artefact is brought into the reconstructed image with parallel MRI. To illustrate this technique, we calculate this PSF metric for GRAPPA reconstruction under various situations.

Theory: We are interested in the PSF changes caused by parallel MRI reconstruction, not by other factors such as T2 decay. In GRAPPA reconstruction, missing lines in *k*-space are reconstructed by combinations of the product between acquired adjacent k-space lines and the reconstruction matrix $\boldsymbol{G}$. In GRAPPA, reconstruction is implemented coil-by-coil, meaning individual coil images are reconstructed prior to forming a final coil combination step [5]. In [4], Robson et al showed that for parallel imaging reconstructions the PSF can be calculated from the reconstruction matrix $\boldsymbol{G}$, coil sensitivities $\boldsymbol{C_l}$ and the harmonic functions ($\boldsymbol{e^{ikx'}}$) as in Eq. 1, where $\boldsymbol{x'}$ is the dummy variable along phase-encoding direction, $\boldsymbol{x}$ is pixel position, $\boldsymbol{k}$ is the k-space index and $\boldsymbol{l}$ is the coil index. The summation is done over all acquired k-space lines and all coils.

$$PSF(x') = \sum_{kl} G_{x,kl} \cdot C_l(x') \cdot e^{ikx'} \qquad [1]$$

Without acceleration, the PSF of each pixel will look like a sinc function and the pixel intensity is therefore dominated by area under central PSF lobe (the region between the first two zero crossings). In accelerated images with residual aliasing artefact, the area under central lobe of the PSF is reduced, whereas the area under the PSF outside centre lobe increases, so a decrease in the ratio of the area of these two regions should correspond to increased artefact. We quantify the artefact by the ratio of PSF centre lobe area to PSF side lobe area, defined as CSR_{PSF} in Eq. 2, with λ as the position of the first zero crossing point on each side of the centre lobe. The centre lobe of the PSF is the weighting of the contribution to the pixel signal from magnetization within the pixel. The side lobes of the PSF give the weighting of the contribution to pixel signal from magnetization outside the pixel. A high ratio will occur where artefacts are potentially low. However, CSR_{PSF} alone is not sufficient to represent the artefact in each pixel, as a high CSR_{PSF} with a weak signal inside the pixel will result in significant visible artefacts while low CSR_{PSF} with weak signal at the aliasing lobes outside the central pixel may result in insignificant artefacts. Therefore, CSR_{rho}, which is defined in Eq. 3 as a summation over PSF(x'), weighted by the reconstructed (artefact free) image, ρ(x'), gives us a better representation of artefact caused by reconstruction.

$$CSR_{PSF} = \frac{\int_{-\lambda}^{\lambda} PSF(x')dx'}{\int_{-\infty}^{-\lambda} PSF(x')dx' + \int_{\lambda}^{\infty} PSF(x')dx'} \qquad [2]$$

$$CSR_{rho} = \frac{\int_{-\lambda}^{\lambda} \rho(x')PSF(x')dx'}{\int_{-\infty}^{-\lambda} \rho(x')PSF(x')dx' + \int_{\lambda}^{\infty} \rho(x')PSF(x')dx'} \qquad [3]$$

Methods: Data from a human brain were acquired from a volunteer after obtaining ethics approval and informed consent. A 2D image was acquired with full gradient encoding with a 256 x 256 image matrix using an 8-channel head coil array on a 1.5T MRI scanner (GE Healthcare, Waukesha, WI, USA). This data was under-sampled to mimic an accelerated acquisition with an outer reduction factor (ORF) of 3 and with 6 fully sampled lines in the centre. The reconstruction PSF and corresponding CSR_{PSF}, and CSR_{rho}, were calculated for each pixel in the accelerated image, as well as the fully gradient encoded one. True coil sensitivities $C_l(x')$ were estimated by normalizing the individual fully gradient encoded coil images to the root-sum-of-squares combination.

Results: Fig 1A shows an example of an unaccelerated image, an example PSF for one pixel in the reconstructed image and a CSR_{PSF} map. Fig 1B shows the same images for the accelerated image reconstructed with GRAPPA. Residual aliasing artefact is visible by comparing two GRAPPA reconstruction images. The PSF shows reduced central lobe and increased side lobes with acceleration. CSR_{PSF} and CSR_{rho} maps show the artefacts caused by parallel MRI reconstruction.

Discussion: Features of the PSF correspond to artefacts in the GRAPPA reconstruction; for instance, side lobes in the PSF correspond to residual aliasing artefacts in the image. CSR_{PSF} illustrates the ratio of the PSF area within the pixel and the rest outside the pixel, and thus indicates where artefacts can potentially occur in the image. CSR_{PSF} has the added advantage that it does not require an artefact free reference image. While CSR_{rho} does require a reference image for its estimate of ρ(x'), it represents the artefacts in a more accurate way by taking both image signal and CSR_{PSF} into consideration. Thus, both CSR_{PSF} and CSR_{rho} are informative metrics to give a quantitative indication of the reconstruction quality that is independent of SNR.

Acknowledgements: We wish to acknowledge support from GE Healthcare, NSERC, and the Canada Research Chairs Program

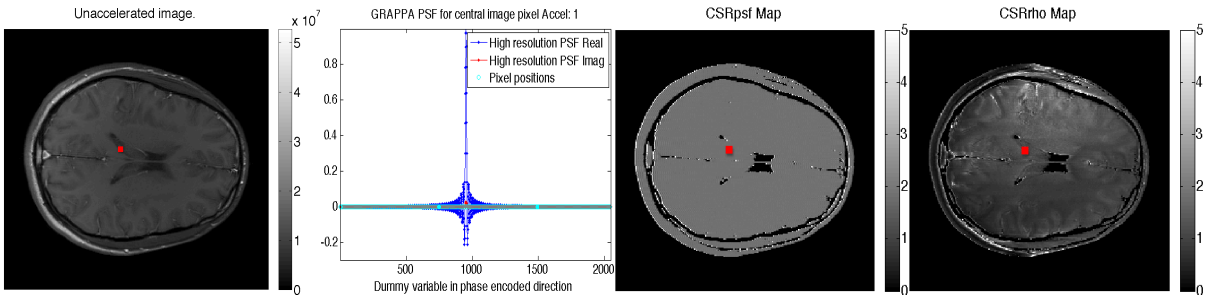

Figure 1A. Magnitude images from an unaccelerated reconstruction (left 1st), magnitude PSF of a pixel of the image (2nd) corresponding to the pixel indicated by the red box, CSR_{PSF} Map (3rd) and corresponding CSR_{rho} Map.

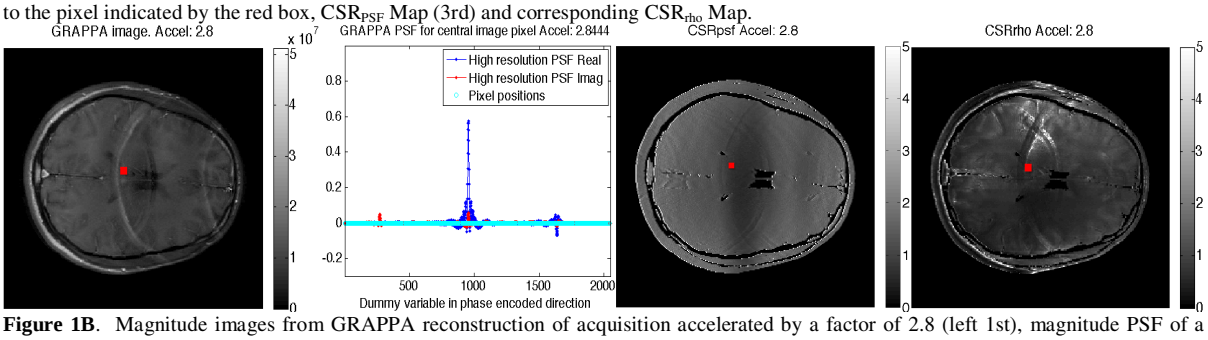

Figure 1B. Magnitude images from GRAPPA reconstruction of acquisition accelerated by a factor of 2.8 (left 1st), magnitude PSF of a pixel (2nd) corresponding to the pixel indicated by the red box, CSR_{PSF} Map (3rd) and CSR_{rho} Map.

References: [1] Pruessmann, et al. MRM 42 (1999): 952-62. [2] Macgowan et al MRM 35, 391-398 (1996). [3] Yeh et al MRM 53 (2005):1383–1392 [4] Robson et al, Proc ISMRM 2007 p1752. [5] Griswold, et al. MRM 47 (2002): 1202-10.