Computationally Rapid Method for Estimating SNR of Arbitrary Parallel MRI Reconstructions

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Introduction: SNR is a common metric of image quality, but its calculation for parallel MRI reconstructions can be challenging. A number of methods of measuring SNR for phased array image reconstructions have been proposed, including direct SNR calculation [1], Monte Carlo based "pseudo multiple replica" SNR estimation [2] and estimation of SNR from multiple acquisitions [3]. Direct SNR calculation can be computationally quick but is not applicable in all cases, while pseudo multiple replica SNR estimation is applicable to any linear image reconstruction but requires lengthy computation times. SNR estimates from multiple image acquisitions are computationally quick, but require additional image acquisition time and any variations between acquisition of the first and subsequent images (e.g. motion, RF instability) cause incorrect estimation of noise.

In one method proposed in the NEMA standard, an image is acquired twice and the difference between the two images is used to measure the noise [2]. To avoid the pitfalls of multiple acquisitions, we propose a new SNR estimation approach that is a hybrid of the NEMA two acquisition and multiple pseudo replica methods in which the difference of two pseudo-images are used to estimate the noise in the image. This gives a computationally rapid method of measuring SNR from a single acquisition.

Theory: Two pseudo-images were reconstructed using the pseudo-replica method [2] to add properly correlated noise to the acquired signal. The pixel-by-pixel difference in the two pseudo-images was used to produce a noise only image. Image noise is calculated over a 3D volume using the following moving standard deviation calculation:

$$Noise(s,q,r) = \left(\frac{\sum_{i=s-m_i}^{s+m_i} \sum_{j=q-m_j}^{q+m_j-1} \sum_{k=r-m_k}^{r+m_k} (V(i,j+1,k) - V(i,j,k))^2}{2(2m_i+1)(2m_j)(2m_k+1)} \right)^{\frac{1}{2}}$$

where V(i,j,k) is the value of the difference between the two pseudo-images at pixel position (i,j,k) and m_i, m_j, and m_k are the boxsize in the i^{th}, j^{th}, and k^{th} directions. A third image with no noise added is used to calculate the signal for the SNR map.

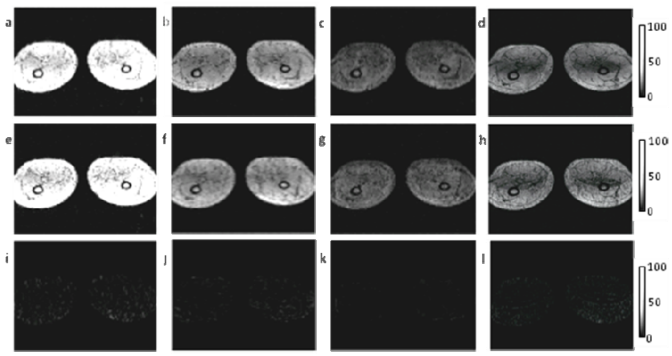

Figure 1: SNR maps of calf using the two pseudo-image (a-d) and Pseudo-replica (e-h) methods for GEM reconstructions with net accelerations of 1, 2.6(1D and 2D acceleration) and 3.2. Difference between SNR maps calculated using two pseudo-image and pseudo-replica are calculated (i-l)

Acceleration Factor	Mean (%)	Standard Deviation (%)	99% confidence interval (%)
1	-0.50	2.0	[-4.6,4.6]
2.6 (1D Acc)	0.73	3.3	[-8.2,7.7]
2.6 (2D Acc)	1.58	4.0	[-7.9,10.4]
3.2 (1D Acc)	1.75	4.6	[-10.2 12.3]

Table 1: Mean, standard deviation, and 99% confidence interval of the percent difference between the two pseudo-image and pseudo replica methods for accelerations of 1, 1.8, and 2.6.

Methods: Fully encoded 3D SGPR calf images were acquired using an 8 channel coil at 1.5T (Signa HDx TwinSpeed, GE Healthcare, Waukesha, WI) from a healthy volunteer after obtaining ethics approval and informed consent. SNR maps were generated using the proposed two pseudo-image method (boxsize=[3,3,3]) as well as the pseudo multiple replica method for Generalized Encoding Matrix (GEM) reconstructions [4] with net acceleration factors of 1, 2.6 (1D and 2D accelerations) and 3.2. Imaging parameters were: TR=7.0 ms, TE=1.98ms, 256x160x44 and BW = ±62.5 kHz. A noise only image was acquired at the same bandwidth to calculate the noise covariance and noise scaling for both the two pseudo-image method and the pseudo multiple replica method.

Results: Figure 1 shows SNR maps of a calf using the two pseudo-image (a-d) and pseudo-replica (e-h) methods for accelerations of 1, 2.6, and 3.2. Absolute difference between the method methods is shown in Figure 1(i-l). Table 1 shows the mean, standard deviation, and 99% confidence intervals of the percent difference between the two pseudo-image and pseudo replica method. Each test of the proposed method was on average within ±1.75% of pseudo-replica method. Confidence intervals showed that each test of the proposed method lies within ±12.3% of the pseudo-replica method 99% of the time.

Discussion: Figure 1d shows an example of a case, 2d acceleration with variable density sampling, where direct calculation of SNR [1] isn't computationally feasible as it would require inversion of a matrix of dimensions of $N_y \cdot N_z \cdot N_{ky}$ by $N_{kz} \cdot N_c$. For such cases, methods such as the two pseudo-image or pseudo-replica method are required with the two pseudo-image method giving accurate results in a fraction of the time (~40X faster). Other parallel imaging cases in which direct calculation of SNR is not tractable include SENSE reconstructions for arbitrary k-space trajectories [5].

An increase in deviation of the two pseudo-image method from the pseudo replica method was seen when comparing the percent difference of a 1D accelerated image to a 2D accelerated image for the same acceleration factor. This result is not surprising as the two pseudo-image method uses a 3D volume to calculate the noise. In a 1D accelerated image, high g-factors will occur at the same pixels for each z-slice making the assumption that each pixel in the volume of interest has the same noise a better approximation. For 2D accelerated images, g-factors will vary in location for each z-slice, making the approximation slightly worse. However, the 2D accelerated SNR maps still perform well as the mean difference was still only 1.58%.

The moving standard deviation calculation spatially smoothes noise throughout the SNR image. Large g-factor spikes will be measured multiple times by adjacent pixels, effectively blurring the spikes over the volume used to calculate the noise. This spatial smoothing effect can be seen in the 3.2 fold accelerated SNR maps. The center of each calf has a region with large noise amplification that was blurred by the two pseudo-image method. By reducing the dimensions of the 3D volume, one could reduce the spatial smoothing resulting in a more accurate result at the cost of precision of the SNR estimate (provided that the 3D volume contains enough pixels to calculate the standard deviation correctly). The optimal box size for SNR calculation has yet to be determined.

Conclusion: The two pseudo-image approach gives a quick and accurate measurement of SNR that is applicable to any parallel MRI reconstruction.

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References: 1) Kellman et al. MRM 2005 54:1439-47. 2) Robson et al. MRM 2008 60:895-907. 3) NEMA Standards Publication MS 1-2001, 2001. 4) Sodickson et al. Med. Phys. 2002 28(8):1629-43. 5) Pruessmann, et al., MRM, 2001 46:638-651.