Data Driven Reconstruction of Inconsistent K-Space Data

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INTRODUCTION: MR data is often corrupted both intra-readout (e.g. flow, off-resonance, T2*) and inter-readout (e.g. spin refocusing, contrast uptake); which has lead to an array of techniques that either model the signal deviations during reconstruction [1-2] or sub-select data [3-4]. Most of these techniques may be difficult to apply when parallel imaging is utilized or require exact knowledge of signal formation. In this work, we develop a framework in which inconsistent data is reconstructed using all available data and a measure of consistency determined from the data itself.

THEORY: MR data (k) is generally assumed to be the exactly known forward transform (E) of an image (x) which is corrupted by noise (ε): $Ex = k + \varepsilon$. In reality, errors in E and time-dependent changes in x result in an additional systematic error term, which can be modeled as additive term (f): $Ex = k + \varepsilon + f$. Error from systematic errors can be mitigated by solving for x using weighted least squares [5]: $x = arg\ min||w(Ex - k)||$, where w is the weighting function: $w = 1 / | f |$ which incorporates systematic uncertainty. Unfortunately, this formulation requires knowledge of $| f |$. Luckily, the solution does not require exact knowledge of $| f |$. We propose to approximate $| f |$ from: 1) estimated differences using signal modeling, requiring estimates of signal corruption or 2) repeated samples using separable intra and inter-readout differences. For example, radial acquisition repetitively sample the center of k-space, allowing $| f |$ to be estimated by subtracting the high SNR k-space signal from a reference signal: $| f | \approx | k_0 - k_{ref} |$

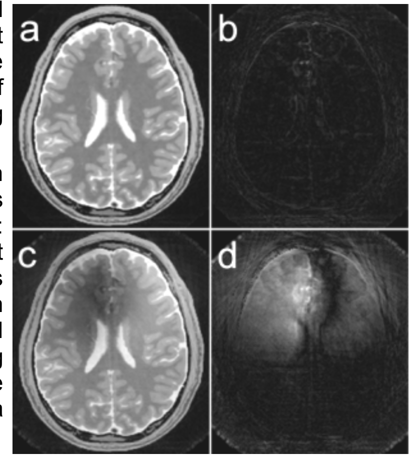

***Figure 1.** Digital phantom images with weighted (a) and unweighted (c) reconstructions and corresponding residual maps compared to ideal image (b/d).*

METHODS: Realistic 2D Fast Spin Echo (RARE / FSE) data was simulated for a single slice from the BrainWeb Database for a 4-half line radial trajectory [6], variable refocusing flip angles [7] (ETL=128, single shot, echo spacing=4.5ms), and coil sensitivities and B0-maps measured from an actual 8-channel head coil. One hundred reconstructions with independent noise realizations were performed using iterative SENSE with and without weighting determined from the center of k-space as proposed above. From these images noise maps were determined and root mean square error (RMSE) was estimated. In-vivo 3D FSE data was subsequently collected utilizing using the same parameters as in the simulation; however, a fully 3D radial trajectory was utilized to acquire 76 shots for 1mm isotropic whole head coverage with a 32 channel head coil in about 2 min. Images were reconstructed using the proposed adaptive scheme with and without weighting based on the center of k-space differences with respect to the central echo.

RESULTS: Figure 1 shows phantom images and residual maps, demonstrating improved image quality with weighting. Unweighted images are biased towards shorter TEs; however, no effective TE can be applied to all tissues. The weighted reconstruction showed reduced root mean square error, 9.6% vs 2.3%, and reduced average noise 1.6% vs 1.1%. Figure 2 shows in-vivo estimation of weights along the echo train dimension and a target echo time corresponding to the 64th echo. Figure 3 shows images reconstructed with the weights in Figure 2 as well as modeled weights along the readout time. Reconstructed images show improved gray/white matter contrast and reduced artifacts from poor gradient and spin echo combination.

DISCUSSION AND CONCLUSION: The proposed reconstruction scheme optimally balances uncertainties from noise error with those from data inconsistency, is compatible with many signal modeling [1-2], and may be advantageous for many parallel imaging and compressed sensing [8] applications. Rather than selecting which data should be utilized at a particular acceleration factor, all available data are supplied and the reconstruction determines whether the errors from acceleration are greater than those introduced by utilizing inconsistent data to choose a solution.

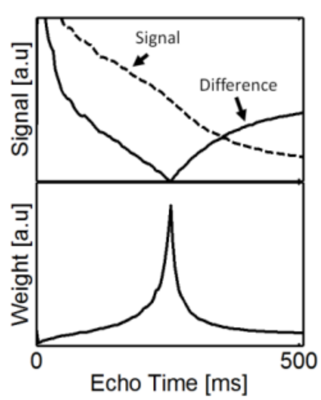

***Figure 2.** Top: Center of k-space signal along the echo train and the difference with respect to the central echo (top). Bottom: The calculated weight for least squares reconstruction.*

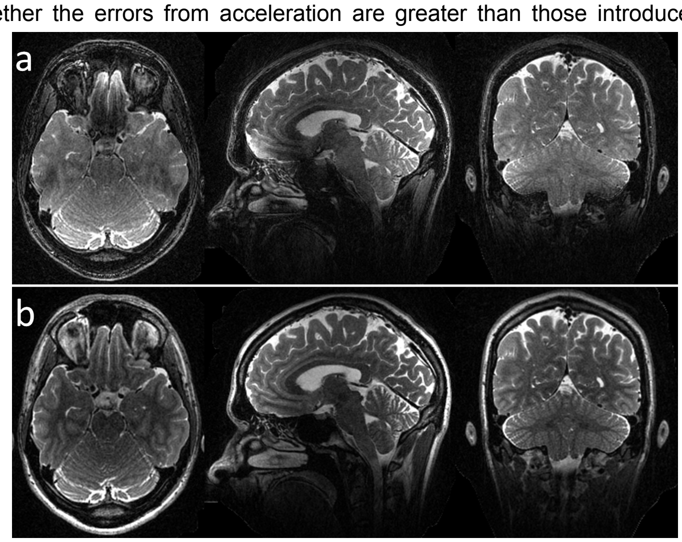

***Figure 3.** Reformatted axial and sagittal images from SENSE (a) and weighted reconstruction using the signal consistency with the central echo (b). Weighted images show better gray white matter contrast and fewer artifacts than the standard reconstruction.*

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REFERENCES: [1] Sutton et al. IEEE 03' 51(2):560 [2] Block et al IEEE 09' 28(11):1759 [3] Song et al. MRM 04' 52(4):815 [4] Koresec et al. MRM 36(3):345 [5] Grabe. Metrologia 01' 38(2) [6] Lu et al. MRM 05' 53(3):692 [7] Busse et al. MRM 06' 55(5):1030. [8] Lustig et al. MRM 07' 58(6):1182