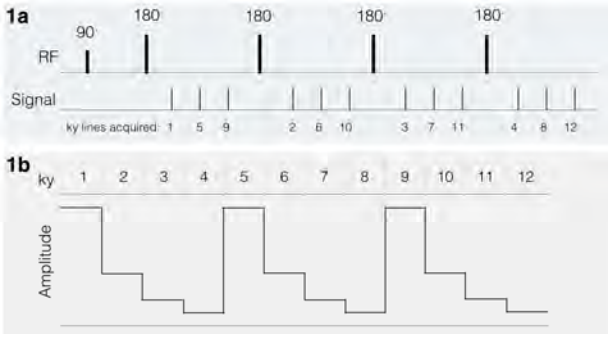
Multi-contrast, parametric and artifact-free images reconstructed from gradient-echo and spin-echo (GRASE) imaging data using projection onto convex sets based multiplexed sensitivity encoding (POCSMUSE)

Mei-Lan Chu[1,2], Hing-Chiu Chang[1], Koichi Oshio[3], and Nan-kuei Chen[1]

[1]*Brain Imaging and Analysis Center, Duke University Medical Center, Durham, North Carolina, United States,* [2]*Graduate Institute of Biomedical Electronics and Bioinformatics, National Taiwan University, Taipei, Taiwan,* [3]*Department of Diagnostic Radiology, Keio University School of Medicine, Japan*

TARGET AUDIENCE: Researchers who are interested in artifacts-free GRASE imaging, multi-contrast imaging, and high-speed parametric mapping.

PURPOSE: 2D gradient-and spin-echo (GRASE) imaging (Figure 1a: [1,2]) is suitable for MRI studies requiring high spatial-temporal-resolution, with 1) reduced susceptibility artifacts as compared with EPI, and 2) reduced SAR than FSE. However, due to the unique amplitude modulation of 2D GRASE k-space data (e.g., Figure 1b), the reconstructed image quality may potentially be degraded by undesirable aliasing artifacts. Here we report a novel approach that can effectively eliminate aliasing artifacts in 2D GRASE data using *projection onto convex sets based multiplexed sensitivity encoding* (POCSMUSE) [3], in which coil sensitivity profiles and inter-CPMG-echo signal variation models are used as the constraints in reconstruction. Furthermore, multi-contrast images can be reconstructed from a single set of GRASE data, reliably enabling parametric T_2 mapping.



METHODS: Figure 1a schematically illustrates a 2D GRASE sequence with 1) four CPMG echoes and 2) 3 EPI readout waveform in each CPMG echo. The amplitudes of the acquired signals are modulated by T_2 decay (Figure 1b), resulting in aliasing artifacts in reconstructed images (e.g., the left most image in Figures 2a and 2b). The four undersampled EPI images (i.e., corresponding to four CPMG echoes) can be represented with: $u_{j,k}(x,y) = \sum_{r=0}^{3} S_j(x, y + r \times FOV_y/4)p(x, y + r \times FOV_y/4)exp(i2\pi kr)W_k$, where $u_{j,k}$ are the aliased signals detected by the j-th coil in the k-th echo (k = 1 to 4); S_j are the coil sensitivity profiles for the j-th coil; the phase term $exp(i2\pi kr)$ reflects the relative k-space trajectory shift along the phase-encoding direction among the four echoes; $W_k = exp(-TE(k)/T_2)$ describes the T_2 weighting function of k-th echo, of which $TE(k)$ is the echo time; and p is the unaliased full-FOV image to be reconstructed. It can be seen that the unaliased proton density (PD) source signals in pixels $p(x, y + r \times FOV_y/4)$ (with r = 0 to 3) can be jointly calculated from full k-space data with prior knowledge on inter-CPMG-echo signal variation patterns (i.e., exponential decay; but without knowing the decay time constant T_2) and coil sensitivity profiles as the constraints, to stabilize the reconstruction [3,4].

Here we use a newly developed POCSMUSE algorithm [3] to solve the above equation, with the following steps. Step 1: An initial guess of PD source image P_i and T_2 weighting matrix $W_{i,k}$ of k-th segment (i=0 at first iteration) are used as the input. Step 2: P_i is multiplied by $W_{i,k}$ and sensitivity profiles S_j of j-th coils. Step 3: Images (from all coils) generated by step 2 are transformed (inverse 2D FT) to k-space signals ($D_{i,j,k}$), which are then further modified through replacing certain ky lines with the experimentally acquired data. Step 4: The modified k-space signals ($D_{i,j,k}$) are transformed (2D FT) to image-domain complex signals. Step 5: Images generated by step 4 are demodulated with sensitivity profiles to generate $D_{i,k}$. Step 6: $D_{i,k}$ are exponentially fitted (across CPMG echoes) to estimate the T_2 time constant, updating $W_{i+1,k}$ for the subsequent iteration. Step 7: $D_{i,k}$ are demodulated with $W_{i,k}$ to generate a new source image P_{i+1} for the subsequent iteration. The iterative procedures are repeated until the source image converges. Note that exponential fitting is included in each POCSMUSE iteration, for better modeling the inter-CPMG echo signal variations and more accurately estimate the weighting terms for the subsequent iteration. Afterward, multi-contrast images can be generated from the reconstructed PD source image and the fitted T_2 time constants.

The new method was evaluated with two sets of human brain data obtained from a 3 Tesla scanner. **1)** *single-shot GRASE (128x128)*: Single-shot GRASE data were obtained four CPMG echoes (TE = 25ms, 50ms, 75ms and 100ms), with 32 EPI readout waveforms in each CPMG echoes. 2) *two-shot GRASE (128x128: hybrid simulation)*: Four data sets were obtained using an 8-shot interleaved spin-echo EPI sequence with an 8-channel coil and TE = 25ms, 50ms, 75ms and 100ms. The hybrid simulation was performed by grouping the 1st and 5th segments from k-space data of TE=25ms, 2nd and 6th segments from k-space data of TE=50ms, 3rd and 7th segments from k-space data of TE=75ms and 4th and 8th segments from k-space data of TE=100ms, thereby creating a two-shot GRASE dataset with the effect of T_2 modulation. The acquired single-shot and simulated two-shot GRASE data were processed with our POCSMUSE algorithm to generate 1) unaliased images corresponding to different CPMG echoes, and 2) parametric PD and T2 maps.

RESULTS: Figures 2a and 2b show (a) single-shot GRASE and (b) two-shot GRASE multi-contrast images and parametric map of a chosen slice, generated by the POCSMUSE reconstruction. The first column shows the GRASE images reconstructed with 2D Fourier transform. The images are corrupted by aliasing artifacts because of the T_2 modulation of k-space data. The 2nd to 5th columns show the reconstructed multi-contrast images, and the last two columns show the POCSMUSE-produced PD and T_2 parametric maps. It can be seen that the images and parametric maps obtained with POCSMUSE are free from aliasing artifacts.

DISCUSSION: The developed method can produce high-quality single-shot and multi-shot GRASE images without aliasing artifacts, as well as PD and T2 parametric maps. In conclusion, POCSMUSE is a general post-processing algorithm, robustly enabling artifact-free and multi-contrast GRASE imaging. It is expected the method can benefit studies requiring high-speed and high-quality imaging.

References:
[1] Oshio, K *MRM* 1991; 20:344. [2] Oshio, K *MRM* 1992; 26:355. [3] Chu, ML *ISMRM* 2014; 0739. [4] Chen,NK *NeuroImage* 2013; 72:41.