Robust Partial Fourier Parallel Imaging Using ESPIRiT and Virtual Conjugate Coils

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Target audience: Physicists and engineers interested in image reconstruction

Introduction: If an image is real, partial Fourier sampling and reconstruction can reduce the amount of data by a factor of two. In practice, B1 inhomogeneity, flow, or off-resonance effects cause phase variations, which must be removed by a low-resolution phase map estimated from a calibration region. Here, we show how ESPIRiT calibration can be extended to produce coil sensitivities which include the image phase. ESPIRiT is a new method for auto-calibrated parallel MRI which computes sensitivity maps from an eigenvalue analysis of the calibration data.[1] ESPIRiT is robust because errors often appear as additional eigenvector maps that can then be taken into account during reconstruction. We show that high-frequency phase effects cause such a second eigenvector map to appear and we exploit this for robust partial Fourier parallel imaging.

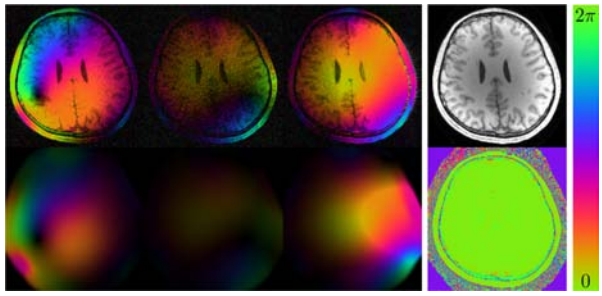

Figure 1: Left: Coil images and sensitivities estimated with the proposed method. The low-frequency phase of the image and the coils is accurately captured. Right: The image combined using the maps has almost no phase.

Theory: Virtual conjugate channels are constructed by flipping and conjugating k-space for all channels.[2] If the image is real, these channels will have complex-conjugate coil sensitivities. Although only relative sensitivities with unknown joint phase are obtained directly with ESPIRiT, the correct phase can be determined up to a sign from the phase difference between physical and virtual channels. Slowly varying phase variations of the image are automatically included into the coil sensitivity maps. For high-frequency phase, ESPIRiT produces a second set of maps in affected image regions.

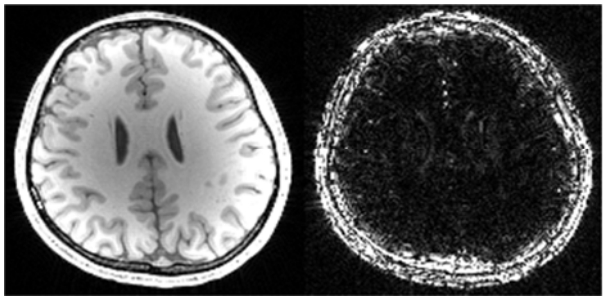

Figure 2: ESPIRiT separates the data into a component with (left) slowly varying phase and (right) high-frequency phase variations.

Methods: Data from a human brain were acquired with 3D FLASH at 3T using a 32-channel coil. The proposed extended ESPIRiT was used to compute two sets of eigenvector maps. A partial Fourier parallel imaging reconstruction using phase-constrained SENSE with only the first set and phase-constrained soft-SENSE[3] with both eigenvalue-weighted sets was then applied to retrospectively undersampled data (acceleration: 3, partial Fourier factor: 5/8).

Results and Discussion: Fig. 1 shows coil images for the first three channels and the first set of sensitivity maps. Using these maps to combine the coil images into a single image yields an image with almost no phase. Fig. 2 shows the images corresponding to both sets of ESPIRiT maps. The image corresponding to the second set contains the high-frequency phase. Fig. 3 shows reconstructions for partial Fourier parallel imaging. While high-frequency phase from fat causes an artifact in the phase-constrained SENSE reconstruction, this is avoided in the proposed method.

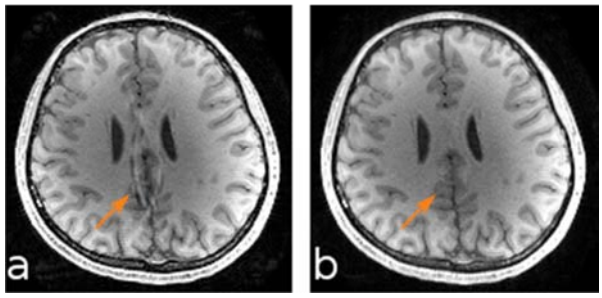

Figure 3: Partial Fourier parallel imaging (R=3, PF=5/8) using phase-constrained (a) SENSE and (b) soft-SENSE with two sets of ESPIRiT maps.

Conclusion: A new extension to ESPIRiT allows the estimation of sensitivities which include image phase. High-frequency phase appears as a second eigenvector map which can be used for robust partial Fourier reconstruction.

References:

1. Uecker at al. ESPIRiT - an eigenvalue approach to auto-calibrating parallel MRI: Where SENSE meets GRAPPA. MRM, Epub 2013.
2. Blaimer et al. Virtual coil concept for improved parallel MRI employing conjugate symmetric signals. MRM, 61:93-102, 2009.
3. Uecker at al. ESPIRiT reconstruction using soft SENSE. Annual Meeting ISMRM, Salt Lake City, In Proc ISMRM 21:127, 2013.