Variable-Density Parallel Image Acquisition and Reconstruction with Partially Localized Coil Sensitivities

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Introduction: Parallel imaging techniques, which are used to increase imaging speed, have recently been coupled with variable-density acquisitions [1-4]. PILS [5] is a very fast reconstruction method that requires minimal knowledge of the coil sensitivities and can be used with variable-density k-space trajectories [4]. However, it suffers from aliasing artifacts when the sensitivities extend beyond the imaging FOV. The acquisition FOVs (FOV_{acq}) supported by the low and high spatial frequency sampling densities are different for variable-density trajectories. Figure 1.a shows the acquisition FOVs in relation to the coil's sensitivity region, FOV_{coil}. With varying kernel extent gridding [6], each set of frequencies supports the corresponding FOV_{acq}s without introducing aliasing artifacts. In this work, we present a new technique that combines individual varying-kernel-extent-gridded coil images -each consisting of a full resolution inner region and a lower resolution outer region- using image-based sensitivity information. The SNR efficiency of image reconstruction is improved over PILS due to averaging of the extended low-frequency regions.

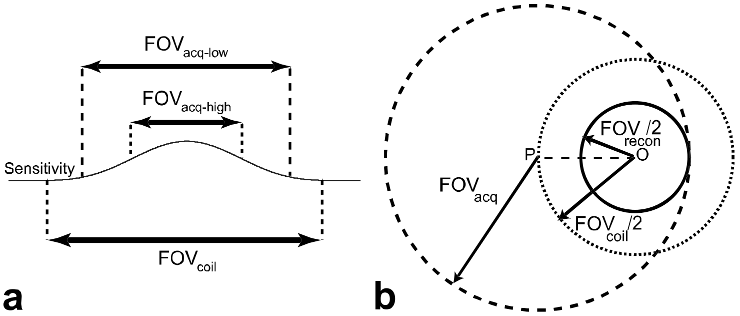

***Figure 1. a:** The sensitivity of an array element is shown along with the acquisition FOVs for low and high spatial frequencies and the spatial-extent of the sensitivity of the coil. **b:** The aliasing-artifact contribution of an input impulse, located at the edge of the coil FOV (point P), will be outside FOV_{recon} (centered at point O), if $\mathrm{FOV}_{acq} \geq (\mathrm{FOV}_{recon}+\mathrm{FOV}_{coil})/2$.*

Methods: In PILS, the localized sensitivities of the coils are utilized to reconstruct individual local FOV images that are usually combined by sum-of-squares (SOS). Because the coil sensitivities can extend beyond FOV_{acq}, the outer regions of each coil's image are cropped to remove aliasing artifacts. If aliasing artifacts due to undersampling of a given set of spatial frequencies are to be avoided over a reconstruction FOV (FOV_{recon}) then $\mathrm{FOV}_{recon} \leq 2\mathrm{FOV}_{acq} - \mathrm{FOV}_{coil}$ must be satisfied as demonstrated in Fig. 1.b. For variable-density acquisitions, the more densely sampled low frequencies can be used to reconstruct a larger FOV ($\mathrm{FOV}_{recon\text{-}low}$) without introducing aliasing artifacts, while the less densely sampled high frequencies support a smaller FOV ($\mathrm{FOV}_{recon\text{-}high}$). Figure 2 displays the reconstruction FOVs for an example 1-D coil array.

To assemble the entire image FOV, individual coil images must be weighted by the conjugate of the coil sensitivity divided by the SOS combination of all sensitivities for optimal SNR prior to combination, assuming array elements are uncorrelated. The sensitivity for each coil is obtained by reconstructing the acquired data after Fourier-domain-truncation and dividing this image by the square root of the SOS combination of images from all coils [7]. For a given pixel, the number of coils with low-spatial-frequency contribution is bigger than those with high-spatial-frequency contribution. To prevent blurring, the optimal estimates pertaining to low and high spatial frequencies are separately computed and the sensitivity estimates are multiplied by indicator functions as the individual coil images do not cover the full-FOV. Assuming $\mathbf{S_i^L}$ and $\mathbf{S_i^H}$ are the low and high frequency images, $\mathbf{C_i}$ is the lower resolution image and $\mathbf{I_i^{L,H} = \{1 \text{ if } S_i^{L,H} \neq 0;\ 0 \text{ otherwise}\}}$ are the indicator functions for the $\mathbf{i^{th}}$ coil, the reconstructed image is: $\mathbf{P} = \{(\sum \mathbf{S_i^L I_i^L C_i^*}) / \sqrt{(\sum \mathbf{I_i^L |C_i|^2})}\} + \{(\sum \mathbf{S_i^H I_i^H C_i^*}) / \sqrt{(\sum \mathbf{I_i^H |C_i|^2})}\}$.

Results & Discussion: Figure 3 shows reconstructions of an undersampled spiral acquisition with an 8-element array. Whereas PILS would normally crop the individual coil images to $\mathrm{FOV}_{acq\text{-}high}$, the proposed method achieves higher SNR efficiency by cropping the low-frequency images to $\mathrm{FOV}_{acq\text{-}low}$. The method is more forgiving to deviations from localized sensitivities than PILS as aliasing artifacts are reduced by varying kernel extent gridding. In SENSE, inaccurate sensitivity estimation leads to aliasing artifacts whereas in our method it may lead to localized blurring due to overestimation of low frequencies. However, such artifacts were not prevalent with the current method of sensitivity estimation. The technique can be applied to most k-space trajectories used in MRI. Fast, artifact-free parallel image reconstructions for variable-density trajectories can be achieved with high SNR efficiency without the need for separate coil sensitivity measurements.

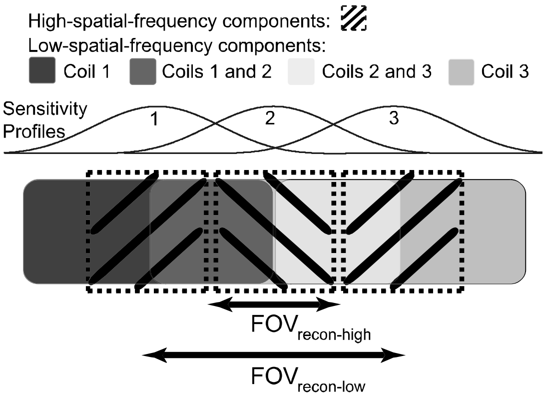

***Figure 2.** Reconstruction FOVs for low and high spatial frequencies of individual coils in a 1-D array. The overlapping low spatial frequency regions from adjacent coils are marked with different colors.*

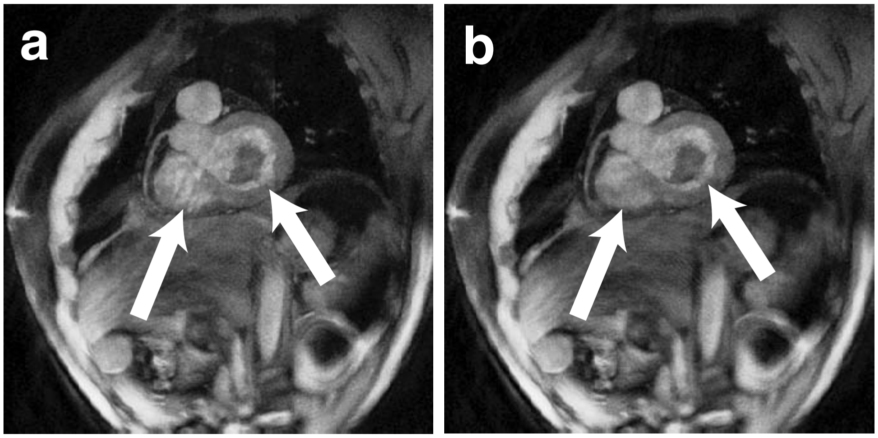

***Figure 3.** A spiral acquisition undersampled by a factor of two, was reconstructed with **(a)** PILS and **(b)** the proposed method. The aliasing artifacts (arrows) noticeable in the PILS image are removed in **b**. The SNR of the image in **b** is higher compared to the PILS image.*

References:
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5. Griswold M, MRM 44:602, 2000. **6**. *Cukur T, "Varying Kernel Extent Gridding Reconstruction", submitted to ISMRM, 2007.* **7**. *Bydder M, MRM 47:539, 2002.*