Highly accelerated parallel imaging using variable density spiral acquisition and spatial adaptive CORNOL reconstruction

Sheng Fang[1], Wenchuan Wu[2], and Hua Guo[2]

[1]*Institute of nuclear and new energy technology, Tsinghua University, Beijing, China, People's Republic of,* [2]*Center for Biomedical Imaging Research, Department of Biomedical Engineering, School of Medicine, Tsinghua University, Beijing, China, People's Republic of*

Introduction: Variable-density spiral (VDS) trajectory is a fast imaging method with the benefits of incoherent undersampling artifacts (1,2). This property of VDS offers itself as a promising candidate for compressed sensing and other nonlinear reconstruction methods such as total variation (3,4). CORNOL is a nonlinear reconstruction method that utilizes the coherence of image structure and has been shown to be effective in suppressing incoherent aliasing artifacts and preserving image details (5). To best exploit both incoherence of aliasing and coherence of image structures, we proposed a new fast imaging method by combining VDS and improved CORNOL (iCORNOL) that is tailored for VDS. The simulation and *in vivo* VDS experiment results demonstrate that this method can achieve a better structure preservation at high reduction factors.

Theory: The non-uniform sampling strategy of VDS generates noise-like aliasing artifacts, which favors the detection of image structures. But it also results in a spatial-varying "noise" variance. Therefore, the spatial uniform thresholding parameter used in the original CORNOL may be sub-optimal. To solve the problem, we proposed the following spatial adaptive operator for VDS reconstruction:

$$\vec{\phi}_i = \{\phi_{ij}\},\ \phi_{ij} = \frac{1}{W_i}\exp\left(-\frac{\|p(i)-p(j)\|_2^2}{h^2}\right),\ h^2 = \left(\frac{\sigma^2}{\sigma_{loc}^2}\right)^{1.5}\cdot\sigma^2$$

where $p(i)$ and $p(j)$ are patches centered at pixel i and j, j is a pixel within the neighborhood of i, W_i is the sum of all ϕ_{ij}, h is the thresholding parameter, which is determined by the background noise variance σ^2 and local variance σ_{loc}^2 of pixel i. If local structure variance is larger than background variance, the thresholding parameter is reduced for better detail preservation. Otherwise, the thresholding parameter is increased for stronger smoothing. Using this operator, the iCORNOL can be formulated as:

$$\bar{\mathbf{u}}_\alpha = \arg\min\left\{\left\|\mathbf{A}\bar{\mathbf{u}} - \bar{\mathbf{f}}\right\|_2^2 + \alpha\sum_{i\in\Omega}\left\langle\vec{\phi}_i, |\nabla u_i|^2\right\rangle\right\}$$

where $\mathbf{A}$ is the encoding matrix, $\bar{\mathbf{u}}$ is the desired image, $\bar{\mathbf{f}}$ is the under-sampled data, Ω is the support of the object and α is the regularization parameter.

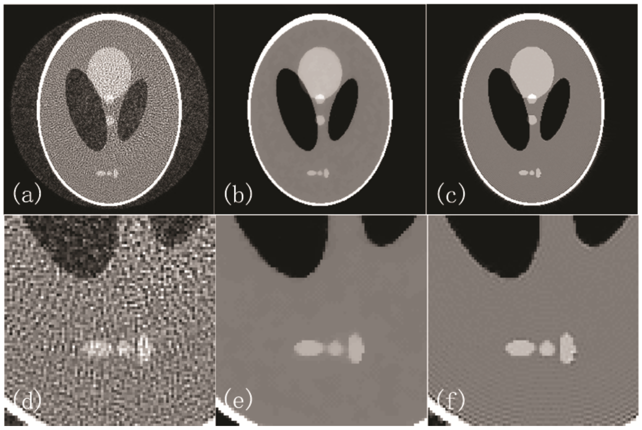

Fig.1: VDS simulation results with a reduction factor of 5. (a) CG-SENSE; (b) TV; (c) the improved CORNOL. (d), (e) and (f) show the zoomed-in part of images of (a) (b) and (c), respectively.

Method: A Shepp-Logan phantom and an 8-channel receive RF coil were used for simulation. A spin-echo VDS sequence was used to acquire a set of i*n vivo* 8-channel images on a 3T scanner (Achieva, Philips, Best, The Netherlands) with: TR = 2500 ms, TE = 80 ms, flip angle = 90°, FOV = 220 mm×220 mm, and image matrix = 256×256, the VDS alpha is 3. A reduction factor of 5 is used for both experiments.

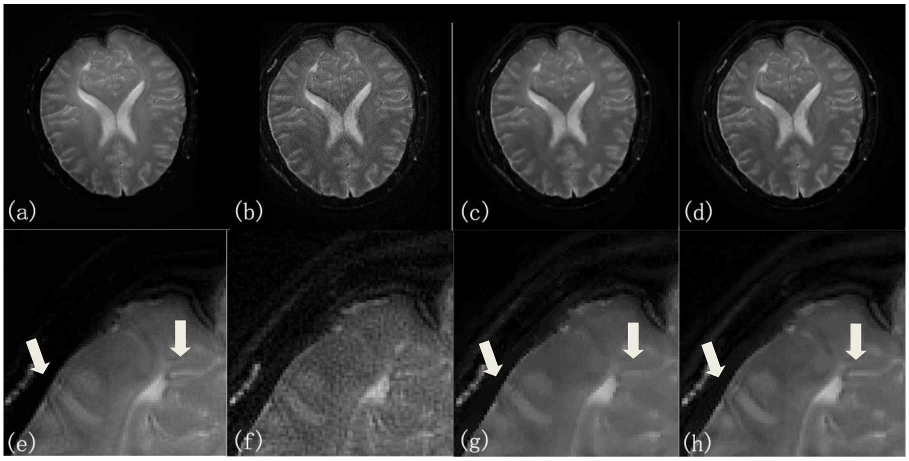

Fig.2: In vivo VDS brain data reconstruction results with a reduction factor of 5. (a) sum-of-squares image; (b) CG-SENSE; (c) TV and (d) the improved CORNOL at a reduction factor of 5. (e), (f), (g) and (h) show the zoomed-in part of (a) ,(b), (c) and(d), respectively.

Results: Figure 1 compares the VDS phantom simulation results of CG-SENSE, Total Variation (TV) regularization and iCORNOL. The CG-SENSE image is severely degraded by noise due to high acceleration factor. TV reduces the noise, but blurs small edges. In contrast, the iCRONOL removes the noise with well-preserved details. Figure 2 compares the *in vivo* VDS results. Similarly, TV smoothes out low-contrast image structure (pointed to by arrows in Fig. 2). And the image reconstructed by the iCORNOL shows a much sharper structure.

Discussion and Conclusions: A fast imaging method combining VDS and iCORNOL was developed. This combination makes the full use of MRI image features by exploiting both the incoherence of aliasing artifacts of VDS and the coherence of image structures. The simulation and *in vivo* VDS experiments results demonstrate that this method can effectively maintain SNR without losing low-contrast image details, even in the presence of high reduction factors. The proposed method may have a further application in high resolution imaging such as diffusion tensor imaging.

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