Self-updating NonLocal Total Variation for highly undersampled variable density spiral reconstruction

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TARGET AUDIENCE: Researchers and clinicians interested in Fast MR data acquisition and reconstruction

PURPOSE: Nonlinear sparsity-constrained reconstruction can effectively improve the quality of image that is reconstructed from undersmapled data set, due to its effective suppression of incoherent aliasing artifact and image noise [1]. Amongst current methods, total variation (TV) is one of such reconstruction that has gained considerable success in compressed sensing and regularized parallel imaging reconstruction [2,3]. However, TV may cause structure loss, if the noise level or artifact level is high. Recently proposed nonlocal TV (NLTV) for image processing task alleviates this problem by weighting TV based on pixel similarity [4] and has been preliminarily applied to Cartesian sense reconstruction [5]. In this study, a fully self-updating NLTV was proposed for variable density spiral (VDS) imaging reconstruction, in order to better preserve image details. The proposed method automatically updates the weight by using a filtered intermediate image, so that no reference image is needed. The wavelet-shrinkage method is used for filtering step to reduce aliasing artifact. The feasibility of the proposed method was tested by *in vivo* VDS experiments. The result demonstrates that this method can effectively suppress noise while preserving better image details than TV at high reduction factors.

METHODS: Nonlocal total variation regularization extends the total variation method by using the following generalized discrete derivatives:

$$\nabla_i^w u = \sqrt{w(i,j)}(u(j)-u(i)), \quad i \in \Omega$$

where u is the discrete image, j is a pixel within the neighborhood of i and the $w(i,j)$ is the weight that depends on the similarity between pixel i and j. Specifically, the weight $w(i,j)$ is defined as:

$$w_{ij}(i,j) = \frac{1}{W_i}\exp\left(-\frac{\|p(i)-p(j)\|_2^2}{\sigma^2}\right), W_i = \Sigma w_{ij}(i,j)$$

where $p(i)$ and $p(j)$ are patches centered at pixel i and j, σ is the background noise variance.

Based on the weighted derivatives, the nonlocal Total variation functional can be formulated as:

$$\bar{\mathbf{u}}^{\lambda} = \arg\min_{\bar{\mathbf{u}}} \left\{ \left\|\mathbf{A}\bar{\mathbf{u}} - \bar{\mathbf{f}}\right\|_2^2 + \lambda \sum_i \left\|\nabla_i^w u\right\|_1 \right\}$$

where $\mathbf{A}$ is encoding matrix, $\bar{\mathbf{u}}$ is the desired image, $\bar{\mathbf{f}}$ is the under-sampled data, λ is the regularization parameter.

Unlike previous NLTV method that uses a pre-computed Tikhonov regularized image for initial weights computation [5], the proposed method calculates the weights from the intermediate results by exploiting the incoherence of VDS aliasing. A wavelet-domain soft shrinkage method was performed to each intermediate image, in order to reduce the incoherent aliasing artifact by promoting the wavelet-domain sparsity. And weights are updated based on the filtered image, so that no reference image is needed.

A spin-echo VDS sequence was used to acquire *in vivo* brain images on a Philips 3T scanner (Achieva, Philips, Best, The Netherlands) using 8-channel coil with: TR = 2500 ms, TE = 80 ms, flip angle = 90°, FOV = 240 mm×240 mm, and image matrix = 256×256, the VDS alpha was set to 3. A reduction factor of 5 was used for both experiments.

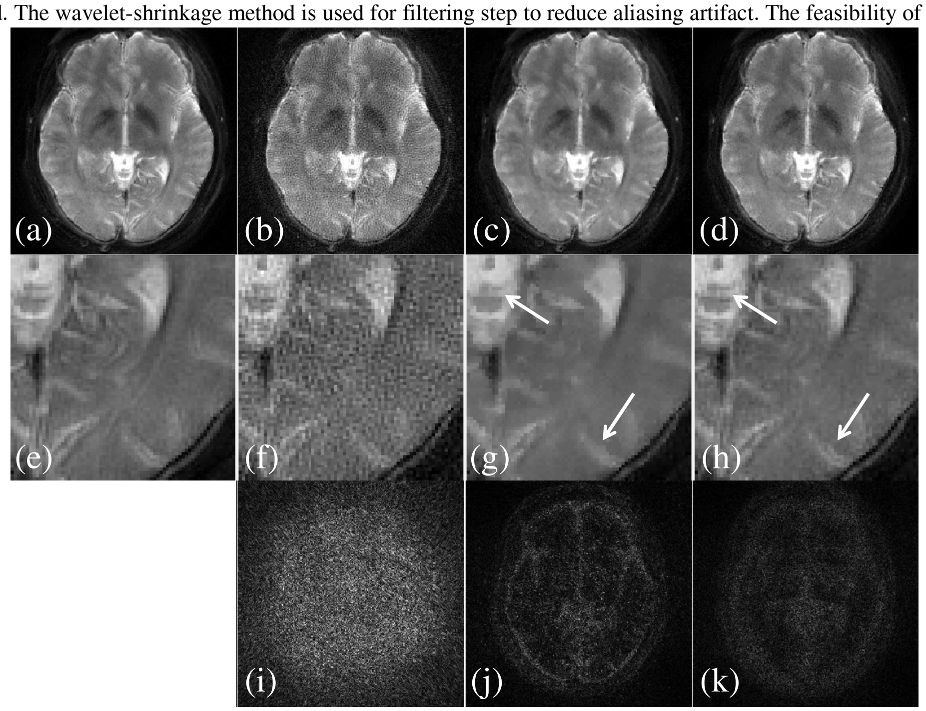

Fig.1 In vivo results with a reduction factor of 5. (a) Sum-of-squares image; (b) CG-SENSE; (c) TV; (d) NLTV;(e),(f), (g) and (h) show the zoomed-in part of (a),(b), (c) and (d) respectively. And (i),(j) and (k)shows the difference map of (b), (c) and (d) with respect to (a) respectively.

RESULTS AND DISCUSSION: Fig. 1 compares the *in vivo* VDS imaging results of CG-SENSE, Total Variation (TV) and NLTV. The CG-SENSE image shows amplified noise. TV effectively removes such noise, but introduces considerable structure loss (pointed to by the arrows in Fig. 1(g)). In contrast, NLTV reconstructed image shows a much sharper structures while the amplified noise was efficiently suppressed as well (pointed to by the arrows in Fig. 1(h)). The difference maps reveal the error distribution of three tested methods. The CG-SENSE image showed amplified noise that covers the entire FOV. The TV image showed obvious error at edges and fine structures in the center of FOV. The NLTV showed a lowest level of error and the error is more uniformly distributed.

CONCLUSION: A Nonlocal Total variation that automatically refines the image-dependent weights was proposed for reconstructing highly undersampled multicoil variable density spiral imaging data. The *in vivo* VDS experiments results demonstrate that this method can effectively suppress noise amplification with better preserved image details at high reduction factors.

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