Suppression of MRI Truncation Artifacts Using Total Variation Constrained Data Extrapolation

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Introduction: The finite sampling of k-space in MRI causes spurious image artifacts which result from signal truncation at the border of the measured k-space. This effect, known as Gibbs ringing, is especially visible for acquisitions at low resolution and mainly presents as an oscillating overshoot of the image intensity near discontinuities. Therefore, the measured data is commonly filtered to reduce the visual appearance of the artifacts at the expense of image blurring. This work demonstrates how the very unspecific assumption of a piecewise-constant object can be utilized to extrapolate the measured data and, thus, to suppress the ringing artifacts without compromising image resolution.

Theory: Strongly varying patterns in an image can be quantified using the total variation (TV) [1], which sums the modulus of jumps between all neighboring pixels of an image $TV=\sum |(x,y) - (x-1,y)| + \sum |(x,y) - (x,y-1)|$. In MRI, the ringing artifacts lead to an increased TV value of the reconstruction relative to that of the true object - assuming that the true object is piecewise-constant to some degree. Therefore, the proposed idea is to add a set of synthetic frequencies to the measured data which is specifically chosen to minimize the TV value of the image that can be reconstructed from the combined measured and synthetic data. This extrapolated data set should then give a more reasonable reconstruction with reduced ringing.
Estimation of the synthetic data can be achieved iteratively by minimizing the TV value of the image reconstructed from the combined data using a numerical optimization procedure where the actually measured data remains fixed. The present work employed the CG-Descent algorithm which is a recent variant of the non-linear conjugate gradient method [2] and requires only evaluation of the TV value and its gradient for a given estimate of the synthetic data.
In practice, experimental MRI data can be significantly contaminated by noise. While the aforementioned algorithm is still able to reduce visible truncation artifacts under these circumstances, it does not reduce image noise as the measured k-space data remains unchanged. However, an additional denoising can be achieved by loosing the fixed bound on the measured data, that is by introducing a data fitting term. In this case, the algorithm not only adds synthetic data for TV minimization, but is also allowed to slightly diverge from the measured data which yields an effective edge-preserving denoising. As a drawback, however, the extension introduces a weighting factor which may cause a loss of object detail if selected improperly.

Methods: Simulations were performed with the numerical Shepp-Logan phantom yielding a matrix of 96 x 96 Fourier samples. MRI experiments were conducted at 2.9 T using a Siemens Magnetom TIM Trio system with a receive-only 12-channel head coil. For demonstration purposes image acquisitions were confined to a simple slice-selective spin-echo sequence with a 200 x 200 mm field of view covered by a 96 x 96 acquisition matrix. All simulations and processing of experimental data were done offline using an in-house software package written in C/C++. Images were reconstructed on a 288 x 288 matrix yielding an extrapolation factor of 3. The proposed algorithm was run for a fixed number of 3000 iterations which takes about 2-3 min on a standard microprocessor.

Results: All figures presented compare solutions obtained with zero-padding (top row) to solutions obtained with the proposed method (bottom row). Figure 1 shows reconstructions of the Shepp-Logan phantom (left column) together with the respective Fourier transforms (right column). It is clearly visible that the zero-padded solution suffers from severe ringing artifacts around all edges of the phantom, while the reconstruction obtained with the proposed method is not degraded by such artifacts and presents with considerably sharper edges. Its Fourier transform reveals that the measured data has been properly extrapolated into the uncovered areas of k-space. Figure 2 shows the application of the proposed method to human brain data. Again, the ringing artifacts obtained for zero padding are significantly reduced when using TV-constrained data extrapolation. Finally, Figure 3 demonstrates the effectiveness of incorporating a data fitting term for the reconstruction from noisy phantom data. While the zero-padding solution suffers from ringing artifacts as well as visible noise patterns, the solution obtained with the extended approach presents with significantly reduced artifacts and reduced noise while nearly all object information is preserved.

Conclusion: The present work demonstrates that the simple assumption of a piecewise-constant object can be exploited to extrapolate measured data in k-space which yields a significant reduction of ringing artifacts. In contrast to filtering approaches the method does not reduce the spatial resolution and rather leads to a mild resolution enhancement due to sharpening of the point-spread-function. If the measured data is seriously contaminated by noise, an extended approach offers edge-preserving denoising by slightly altering the measured data in addition to supplementing synthetic data.

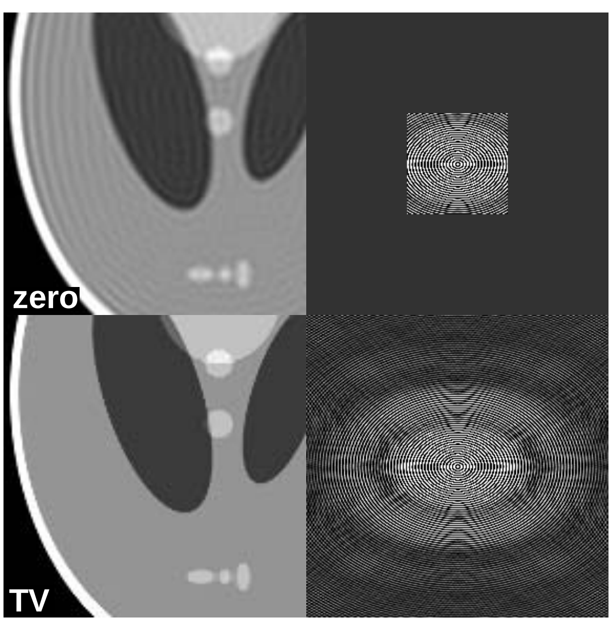

Fig. 1: Shepp-Logan phantom with Fourier transform

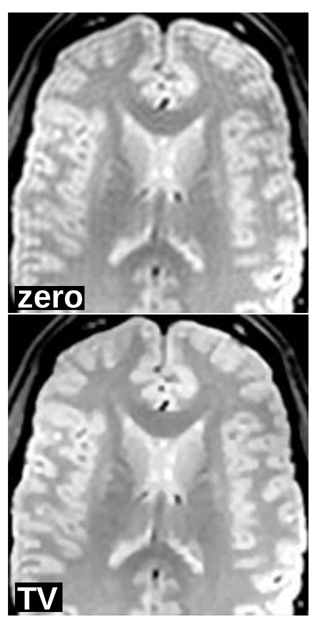

Fig. 2: Human Brain in vivo

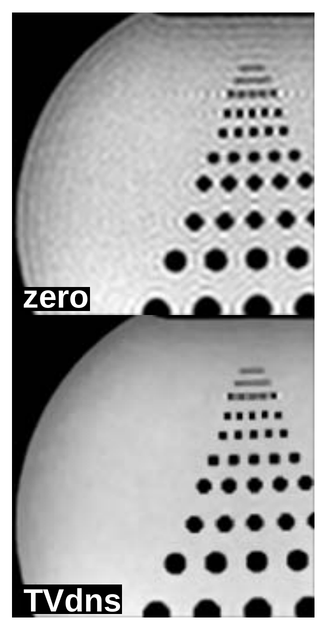

Fig. 3: Noisy phantom data

References

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