Reference Histogram Constrained Artifact Suppression (RHiCA) for Incoherently Undersampled Magnetic Resonance Imaging

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Introduction

The increasing need to reduce measurement time holds a demanding task for modern magnetic resonance imaging (MRI). Several different approaches have recently been reported aiming at accelerating MRI acquisitions. In non-dynamic MR imaging numerous approaches are based on utilizing spatial redundancies in the image. The straightforward approach to save measurement time in single acquisition of static objects is the reduction of the amount of acquired data per k-space. However, the continuous decrease in sampling density leads to unavoidable aliasing or undersampling artifacts in the reconstructed image. The most prominent approach, Compressed Sensing (CS) [1-4] employs the special nature of artifacts resulting from incoherent sampling schemes to suppress artifacts using a non-linear optimization based reconstruction. In this work we present an alternative method based on the specific signature of radial undersampling artifacts in histogram space and relying on a minimization algorithm. We successfully illustrate, that applying the Reference Histogram Constrained Artifact (RHiCA) reduction leads to an effective suppression of undersampling artifacts.

Methods

Streaking artifacts in a radially acquired MRI reconstruction result in a broadening around the centre of peaks in an intensity histogram while no shift of the original distribution appears. We propose to correct for aliasing artifacts due to undersampling on the basis of the corresponding intensity histograms.

An undersampled k-space subject to reconstruction is a subset of a fully sampled k-space where missing projections are substituted with zero entries. Reconstructing this zero-filled k-space to the original full resolution causes aliasing artifacts when violating the Nyquist theorem. However, by rebinning the measured data, one can reconstruct an image of reduced resolution without any aliasing artifacts. While this operation reduces the detail information included in the reconstructed image, the line width of according histogram peaks are reduced and peaks overlapping due to streaking are separated. Thus, the intensity histogram of the low-resolution image serves as a reference histogram to compensate for streaking in the full resolution histogram. The RHiCA method is based on the correction of undersampling artifacts by adapting the impaired histogram to a reference histogram. The reconstruction is obtained by solving the following constrained optimization problem:

$$Im_{res} = \underset{x}{argmin}||\Phi(x) - y|| + \lambda_H||D_H|| \quad \text{with} \quad D_H = |H_{tar} - H_{ref}|$$

Here y is the acquired raw data, λ_H is the regularization parameter, weighting the histogram constraint D_H, namely the difference of the reference histogram H_{ref} and the target histogram H_{tar}. The first term in Equation 1 denotes the raw data fidelity, that is, the difference between the acquired k-space data y and the back transformed image after each iteration step, where Φ denotes the transformation into image space.

In order to assess the performance of RHiCA a numerical phantom was implemented that allows for the simulation of the reconstruction of small structures such as small vessels and capillaries. The phantom was designed as a 256^2 zero valued pixel matrix in which 150 elliptic objects (long axis: 20 pixels, short axis: 4 pixels) were added. The original numerical phantom was sampled with 101 spokes, thus an undersampling factor of 4.

Additionally a 2D head MRI of a healthy human volunteer was performed. Data was acquired with a 3.0 T MR-scanner (Magnetom Trio, Siemens AG, Healthcare Sector, Erlangen, Germany) using a multi-slice BLADE Sequence in transversal orientation (TR = 9 s, TE = 145 ms, slice thickness = 5 mm, matrix = 320, FOV = 220 x 220 mm^2). To generate an undersampled reconstruction only a number of 81 spokes were used, which corresponds to an undersampling factor of 6.

Subsequently, the raw data was reconstructed according to the Nyquist theorem in order to generate a reference image and histogram.

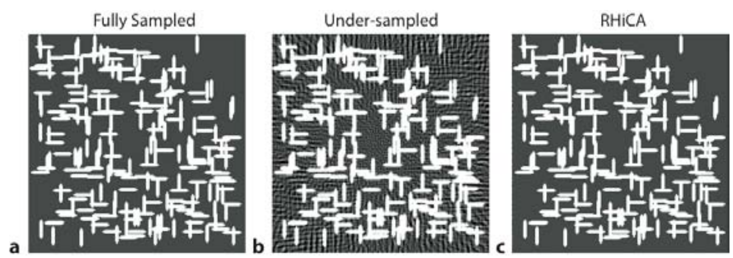
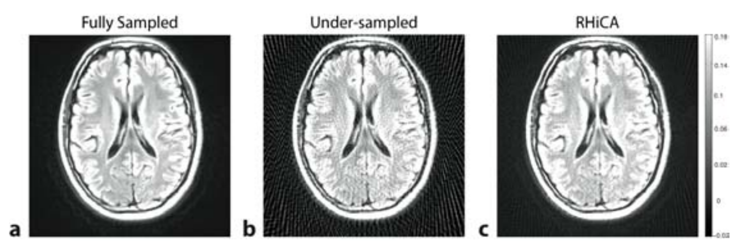


Fig. 1. Result of RHiCA on a numerical phantom. **(a)** Reconstruction of the fully sampled (402 spokes) numerical phantom. **(b)** Zero-filling reconstruction from only 101 spokes, showing strong streaking artifacts. **(c)** Result after application of the RHiCA algorithm.



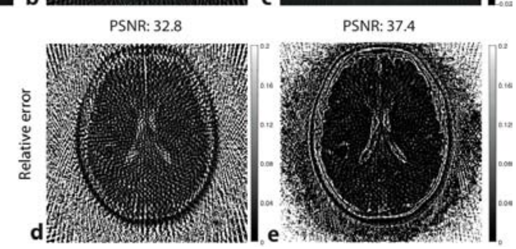


Fig. 2. Results of the in vivo simulation using a resampled 2D MRI slice of a human head. **(a)** Reconstruction of a measurement with 501 spokes and the corresponding **(b)** Undersampled reconstruction with a factor of 6.2. **(c)** Resulting image after RHiCA reconstruction. **(d/e)** Relative error of the undersampled reconstruction and the RHiCA reconstruction.

Results

Figure 1 illustrates the results of the application of RHiCA on the described ellipse phantom. Figures 1a-1c display the fully sampled (402 spokes), the undersampled (101 spokes) and the image after RHiCA application. By correcting the histogram, the algorithm managed to suppress almost all of the apparent streaking artifacts in figure 1b, while maintaining details in the image, such as crossing ellipses.

Figure 2 presents the result of RHiCA applied on a head MRI slice. The undersampled reconstruction in Figure 2b shows strong streaking artifacts compared to the fully sampled reconstruction in Figure 2a. While in the image after RHiCA application in Figure 2c artifacts are almost completely removed without perceptual loss of image quality. Figures 2d and 2e present the relative error of the undersampled filtered backprojection reconstruction (fig. 2d) and the result after RHiCA application (fig. 2e), with significantly reduced values in all image sections and an increase of 4.6 dB in the peak signal to noise ratio.

Discussion

We have successfully presented the theory and application of RHiCA on both numerical and in vivo MRI simulation. We assessed the performance of RHiCA on static single frame objects, using a low-resolution Nyquist reconstruction as reference for the correction. In in vivo acquisitions of RHiCA we achieved an increase in the PSNR of 4.6 without perceptual loss in image quality.

References

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