Composite Histogram Constrained Artifact Suppression (CHiCA) for Dynamic Cardiac Magnetic Resonance Imaging

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Introduction

Reduction of overall measurement time and the ability to temporally resolve fast physiological processes proves a demanding task for modern magnetic resonance imaging (MRI), especially for techniques such as dynamic contrast enhanced MRI (DCE MRI) and cardiac function imaging. In dynamic MRI several techniques [1] aim to take advantage of the redundancies in the spatial, temporal or spatiotemporal domain to reconstruct images from undersampled data sets. TSENSE [2], TGRAPPA [3] and HYPR [4] are representative techniques in the category of subsequent spatial and temporal correction. While dynamic contrast changes are recovered very effectively using previously mentioned methods, motion hinders these techniques from recovering the original image precisely. In this work, we present an alternative method based on the specific signature of undersampling artifacts in histogram space and relying on a minimization algorithm. We successfully illustrate, that applying our Composite Histogram Constrained Artifact (CHiCA) reduction leads to an effective suppression of undersampling artifacts in dynamic radial MRI.

Methods

Streaking artifacts in radially acquired MRI reconstructions result in a broadening around the peak's centre in an intensity. We propose to correct for aliasing artifacts due to undersampling on the basis of the corresponding intensity histograms. An interleaved array of equidistant sampling angles is implemented to measure consecutive undersampled time frames. Subsequently, single time frames can be reconstructed with high temporal resolution, but impaired from aliasing. Additionally, it is possible to calculate composite raw data using *m* consecutive k-spaces in a sliding window manner, where *m* is the used undersampling factor. A reconstruction from the composite raw data results in an image of lower temporal resolution but without any undersampling artifacts. Subsequently, in order to correct for artifacts in the single time frames we use the histogram of the composite image. The CHiCA reconstruction is obtained by solving the following constrained optimization problem using a non-linear conjugate gradient approach implemented in Matlab (Mathworks, Natick, US):

$$Im_{res} = \underset{x}{argmin}||\Phi(x) - y|| + \lambda_H||D_H|| \quad \text{with} \quad D_H = |H_{tar} - H_{ref}| \quad (1)$$

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. The second term of Equation 1 is a weighted regularization, comprising the difference between the perturbed target and the reference histogram.

To assess the application of CHiCA on dynamic data a numerical phantom was implemented, simulating a human thorax in a typical DCE MRI examination. The simulation covers 10 cardiac cycles with a total acquisition time of 10 seconds. The inflow of the contrast agent (CA) starts at the beginning of the second cycle and follows the cardiac intensity evolution described by Su et al. [5]. The dynamic evolution was sampled with a rate of 40 frames per second and 39 spokes acquisition, corresponding to an undersampling factor of 10.

The performance of CHiCA on dynamic in vivo data was evaluated on a time resolved MRI image series of the heart of a healthy volunteer. One single cardiac cycle was initially sampled with a 1.5 T MR-scanner (Siemens AG, Healthcare Sector, Erlangen, Germany) using a 2D time-of-flight sequence (TR = 44.7 ms, TE = 1.49 ms, slice thickness = 5 mm, FOV = 325x400 mm^2). To generate an interleaved undersampled data set, only 51 spokes per acquisition and a cropped image matrix of 100^2 pixels were used. Five consecutive interleaved radial raw data sets with alternating angles form the composite data set and provide the reference histogram.

Results

Figure 1 illustrates the results of CHiCA applied to the described numerical simulation. The native time frame (Fig. 1a, far right column) presents the effective suppression of undersampling artifacts present in the few view reconstruction (middle column), resulting in an image comparable to the fully sampled reconstruction (left column). The dynamic cut through the heart chamber in Figure 1b illustrate the artifact suppression over the whole dynamic dataset comprising inflow and washout of the contrast agent. Exept for the minor residual artifacts in the myocardium CHiCA efficiently leads to a suppression of artifacts throughout the entire dynamic measurement.

Figure 2 illustrates the results of artifact reduction using CHiCA on a time resolved cardiac MRI. The displayed time frame is set during the systolic phase. The CHiCA reconstruction in the third column shows almost no remaining artifacts, while still maintaining details. It is seen that even small and highly varying contrast objects, such as a pulmonary vessel marked by the dashed circles, can be accurately recovered by the CHiCA algorithm. The solid white circles depict an enlarged view of the blood vessel. CHiCA is able to not only recover the object, but also sharpen the edges, even compared to the fully sampled image FBP reconstruction.

Discussion

We have successfully presented the theory and application of CHiCA on both numerical and in vivo MRI simulation. We assessed the performance of CHiCA on dynamic image sets, comprising both motion and contrast changes. Since the intensity histogram is naturally independent from motion, time resolved MRI is a perfect match for the CHiCA reconstruction. The acquisition of real radial data of DCE measurements is subject to current and further investigations.

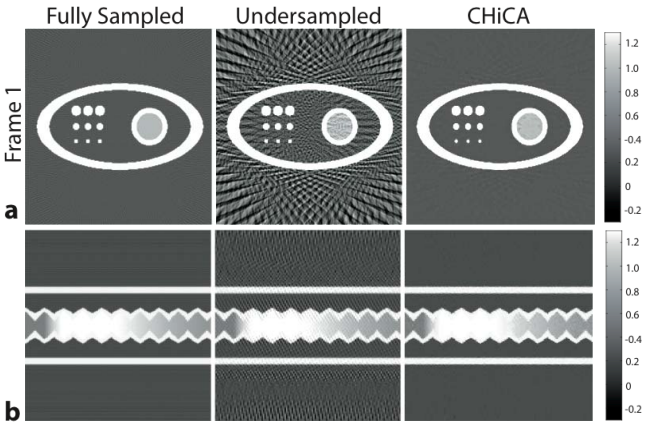

Fig. 1. Representative results of the numerical DCE MRI simulation. **(a)** The fully sampled (402 spokes), undersampled (39 spokes) and the CHiCA reconstruction (39 spokes) in the first time frame. **(b)** Time dependent cut through the heart chamber in figure 1a, illustrating heart beat and the inflow and washout of the contrast agent.

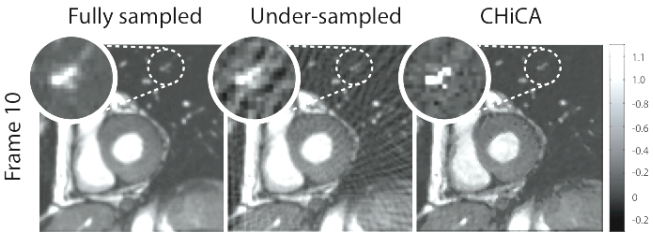

Fig. 2. Excerpt of the results from the in vivo simulation using a time resolved set of MRI images of the human heart. The chosen section includes the two-chamber view of the heart, as well as a part of both kidney and spleen and a large portion of the pulmonary parenchyma. The dashed circles mark the cross section of one particularly interesting pulmonary vessel. For better visibility the solid line circles depict a zoomed view with enhanced contrast settings.

References

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