Image quality parameters in MR images, reconstructed by using compressed sensing

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Introduction:

Compressed sensing is a technique that allows accelerating data acquisition in the presence of sparse or compressible signals ([5], [6], [7]). Especially, in magnetic resonance imaging, where measurements may be time consuming, compressed sensing might give a chance to reduce the scan time. However, up to now there are no studies that examine basic imaging parameters like image noise and spatial resolution for compressed sensing. Therefore, aim of this study was to introduce methods to determine image quality parameters suitable for compressed sensing reconstruction and to evaluate the application of these methods in compressed sensing of cardiac CINE imaging.

Materials and methods:

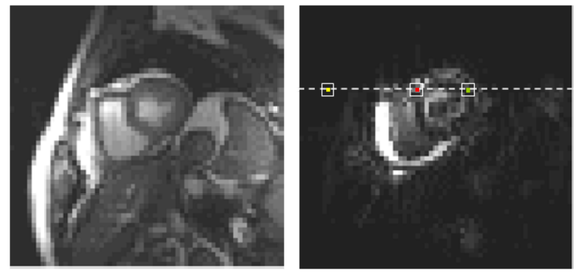
Conventional MR Imaging can be assumed to be a linear and spatially invariant transformation, which can be described by a single point spread function (PSF). In contrast, compressed sensing is both nonlinear, and non-stationary.

While for differentiable transformations a local linear approximation is possible (zeroth and first term of the Taylor series), the non-stationarity leads to different point spread functions at different positions.

Functional cardiac CINE images were acquired (TrueFisp, 3T Trio, Siemens Healthcare, Erlangen, TR 3.1ms, TE 1.4ms, temporal resolution 47 ms) and undersampled for all simulations. While the individual time-frames were undersampled according to an incoherent pattern, a complete k-space was acquired for the temporally averaged image (like in UNFOLD [1] or Auto-SENSE [2]). From these data the sparse difference images between the average image and the individual time frames were reconstructed using an algorithm proposed by Ma et al. [3].

Point spread functions or spatial response functions for each pixel were determined by first adding a small perturbation (within the validity of the linear approximation) to the pixel in the image, then calculating the corresponding k-space, reducing the data to the undersampled time frame, performing an additional compressed sensing reconstruction and determining the difference to the original compressed sensing reconstruction. From these point spread functions for each pixel image quality factors like the spatial resolution (i.e. width of the main lobe) or the aliasing were determined.

An image noise distribution (g-factor) map was calculated using the method proposed by Robson et al. [4].



a) b)

***Fig. 1) a)** reconstructed time frame **b)** difference image between the time frame and the averaged image (dynamics), 1D cross section*

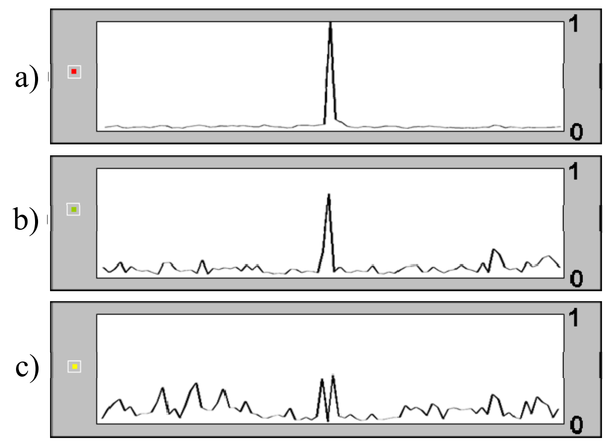


***Fig. 2)** point spread functions of three different locations (marked on the dashed line in 1b))*

Results:

In Fig. 1a), the described reconstruction of a representative time-frame of the CINE is shown, in Fig. 1b) the reconstructed dynamics, i.e. the difference between the average image and the timeframe are displayed. In fig 2) 3 PSFs are depicted exemplary. In Fig. 2a) the delta peak perturbation was seeded on a pixel with high amplitude, which leads to a PSF close to the PSF for a standard Fourier transform. In Fig 2b) the PSF shows blurring and significant aliasing from distant locations. Here, the amplitude of the main lobe falls below 1. In pure noise pixels (Fig. 2c)) the PSF does not reflect a reasonable transformation of the delta peak perturbation.

In Fig. 3) the results of the quality analysis applied to the complete difference image are displayed. In the maps on the top, the spatial dependence is outlined. A threshold for the signal amplitude (1% S_{max}) was set.

The dependence of the width of the main lobe from the magnitude on the signal in the pixel shows that values of a width close to 1 are found, where the magnitude of the image pixel is >20% of the maximum value (Fig 3a)). The g-factor map shows the pixels where noise is suppressed. However, for the large pixel amplitude no significant noise suppression is observable.

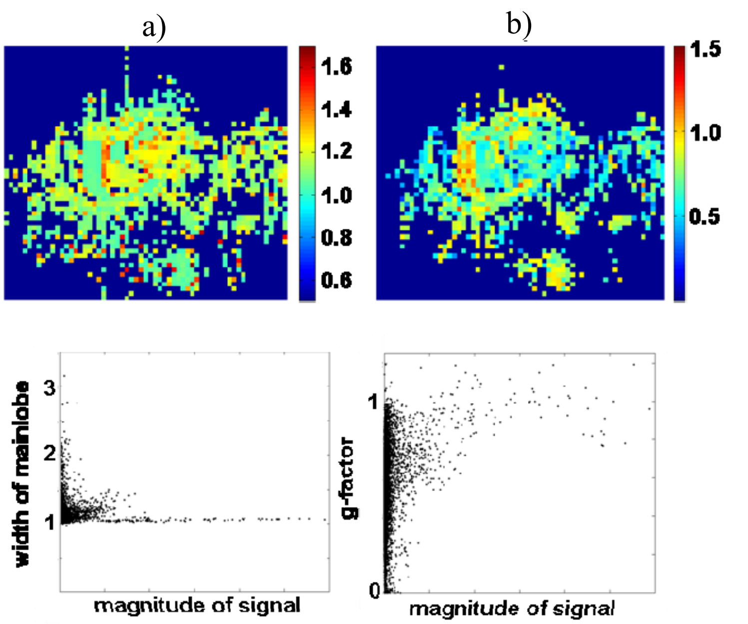


***Fig. 3 a)** width of the main lobe in every pixel of the reconstructed dynamics **b)** g-factor of the reconstructed dynamics*

Discussion:

The abstract introduces a method, which describes a nonlinear algorithm by a linear approximation. The non-stationarity of the transformation manifests in different point spread functions for every pixel.

The proposed method allows determining the resolution as well as the aliasing energy of nonlinear and non-stationary imaging processes. Together with g-factor maps this will allow to compare quantitatively the quality of different sampling strategies, acceleration factors and reconstruction algorithms for compressed sensing in the future.

References:

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