Improved Compressed Sensing reconstruction in dynamic contrast enhanced MR Angiography by means of Principal Component Analysis (PCA)

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Introduction: Recently, the concept of Compressed Sensing (CS) has been introduced to the field of Magnetic Resonance Imaging (MRI) [1,2]. It has been shown that CS allows for a significant acceleration in the rate of data acquisition for MR Angiography (MRA) or real time cardiac imaging [2]. CS operates by taking advantage of the fact that a small fraction of the fully-sampled data, far below the sampling rate dictated by the Nyquist sampling theorem, is required in order to yield unaliased images if the object to be imaged can be represented in a sparse manner in an arbitrary basis and if the sampling scheme features incoherent artifacts. However, the CS approach tends to fail at high acceleration factors and suffers from severe artifacts if the noise in the data exceeds a certain limit. In order to overcome these limitations we propose to employ the concept of Principal Component Analysis (PCA) similar to [3] in the CS reconstruction process. We show that this strategy results in superior image quality in MRA applications and allows for significantly higher image acceleration factors compared to CS reconstructions that use solely CS.

Theory and Methods: MRA data of the head was acquired using a 3D FLASH sequence in sagittal image orientation with a 33% asymmetric radial read-out trajectory in-plane (k_x,k_y) and a 50% asymmetric Cartesian phase encoding in the z-direction on a 1.5T whole body scanner equipped with a 12 channel head array. The following sequence parameters were employed: FOV = 240x240x80mm^3, α = 15°, TE = 1.59ms, TR = 3.21ms, 12 radial projections (bit-reversed), 32 partitions, 80 repetitions. The data was reconstructed onto a 192x192x44 matrix at a frame rate of 1.2s per volume. The CS-PCA reconstruction was performed as depicted in Fig 1. After inverse Fourier Transformation (FFT) in the z-direction the undersampled radial data was gridded onto a Cartesian k-space using GROG [4]. After inverse 2D FFT of each individual partition and subsequent adaptive coil combine (CC) of the individual channels [5], a temporal average was generated from the first 30 frames (before arrival of the contrast bolus) and subtracted from the remaining time frames (with contrast bolus) in order to remove the residual static tissue in the brain. After that the PCA was applied along the temporal direction in order to derive a set of basis vectors containing an estimate of the main contrast dynamics. After PCA, the dynamics are modeled in the first few principal components; the lower order components can be discarded. The new basis vectors are then used to convert the data into the new, heavily compressed basis which exhibits high SNR in the first few components. After an initial CS step the data are transformed back to the original basis (PCA^{-1}), redistributed to the individual channels (CC^{-1}), and finally updated with the original data in the Cartesian k-space (data consistency). After that an update of the basis in the image space is employed by applying the PCA prior to the next CS step and so forth. This procedure was repeated until convergence is achieved. Due to the iterative update of the basis after each CS step and due to data consistency constraint, the reconstruction is self-calibrating and does not require any prior knowledge about the dynamics. The CS algorithm used employed the minimization of the l1 norm of the images after subtraction of the static tissue. In addition, strict data consistency according to the method proposed in [6] was used allowing for regularization and calibration free image reconstruction.

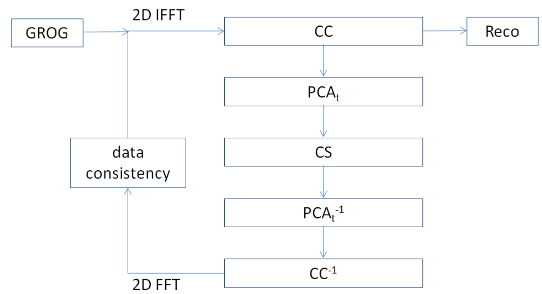

Fig 1: Schematic of the CS-PCA reconstruction process

Results: In Fig. 2, Maximum Intensity Projections (MIPs) of the data in the sagittal view at three different time frames are displayed. In addition, in order to demonstrate the benefits of this approach, reconstructions using (a) conventional convolution gridding (b) conventional CS and (b) CS with PCA are shown.

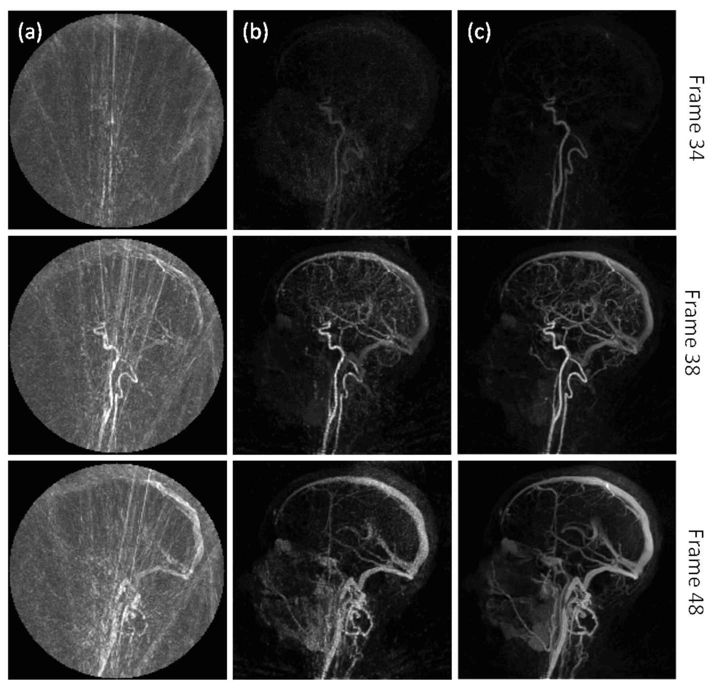

Fig 2: Maximum Intensity projection (MIP) reconstructions at three different time frames out of 80 (frame rate 1.2 per second) after (a) conventional convolution Gridding (b) CS reconstruction alone and (c) proposed CS reconstruction employing PCA.

Conclusion: It has been demonstrated that PCA can significantly improve CS reconstructions in contrast enhanced MRA, allowing for both increased spatial and temporal resolution. In future work the performance and limitations of this approach will be investigated in applications showing more complex dynamics such as e.g. real-time cardiac imaging.

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