Accelerated Cine DENSE using Variable Density Spirals and Compressed Sensing with Parallel Imaging

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Target audience: Researchers interested in the development of cardiac MRI methods.

Introduction/Purpose: Cine DENSE (Displacement Encoding with Stimulated Echoes) provides accurate and high-resolution displacement and strain imaging of the heart; however, image acquisition times are relatively long and, due to properties inherent to stimulated echoes, signal-to-noise ratio (SNR) is relatively low. Accelerated cine DENSE could substantially shorten scan times and/or provide improved temporal resolution; however, the low SNR, requirement to preserve phase information, and cardiac motion present technical challenges. We investigated variable-density spiral trajectories with compressed sensing (CS) and parallel imaging (PI) for this application.

Methods: A variable-density spiral cine DENSE sequence was implemented where the center of k-space was fully sampled and the outer portion of k-space was undersampled. Spiral interleaves were distributed uniformly within each cardiac phase and rotated by the golden angle through different cardiac phases to achieve randomness in time. For image reconstruction, we used the Block LOw-rank Sparsity with Motion-guidance (BLOSM) CS method [1], combined with SENSE [2]. This algorithm exploits matrix low-rank sparsity within motion-tracked regions of SENSE-combined images (Fig 1). Sensitivity maps were calculated from temporally-averaged DENSE phase reference data to avoid phase aliasing when estimating coil sensitivities. Non-uniform FFT [3] was used for transforming data between k-space and the image domain. For comparison, undersampled datasets were also reconstructed using SENSE without CS.

Short-axis cine DENSE images of the left ventricle were collected from 5 healthy volunteers on a 1.5T MRI scanner (Avanto, Siemens) with a body-spine combined array RF coil (5 channel). Fully-sampled datasets with 2D in-plane displacement encoding and 6 to 8 spiral interleaves per image were acquired within a long breathhold (20 to 26 heartbeats), and prospectively accelerated datasets at rates 2 and 4 (with 4 and 2 spiral interleaves per image) were acquired within much shorter breathholds of 14 and 8 heartbeats, respectively. The fully-sampled datasets provided reference images, and retrospective undersampling of these datasets was used to evaluate the new methodologies. Prospectively acquired undersampled cine DENSE datasets demonstrated true acceleration. Imaging parameters included field of view (FOV) 280-320x280-320 mm^2, spatial resolution 1.8-2.2x1.8-2.2x8 mm^3, ramped flip angle with the last flip angle = 15°, TR 9.8 ms, TE 1.3 ms, temporal resolution 19.6 ms, and cardiac phases 35-38.

Image quality was analyzed by measuring the mean squared error (MSE) for retrospectively undersampled data and the SNR for all the data. Myocardial strain was computed using standard methods [4]. Using the retrospectively undersampled and prospectively accelerated data, segmental circumferential stain (E_{cc}) was compared to the fully-sampled data .

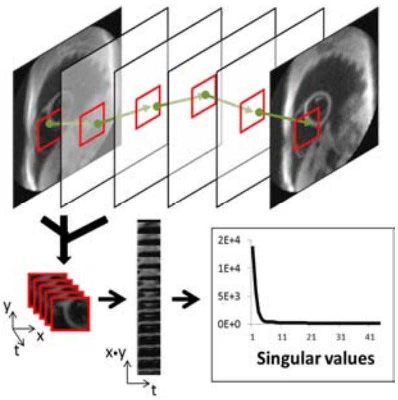

Figure 1. BLOSM-SENSE exploits matrix low-rank sparsity within motion-tracked regions from SENSE-combined images. After the multi-channel data are combined with SENSE, regions (blocks) are initialized on the first image. Each block is motion tracked to the succeeding images through time using motion trajectories from image registration. The blocks are gathered into a 3D cluster and further rearranged into a 2D matrix with high spatial-temporal correlations. The sparsity is exploited using singular value decomposition.

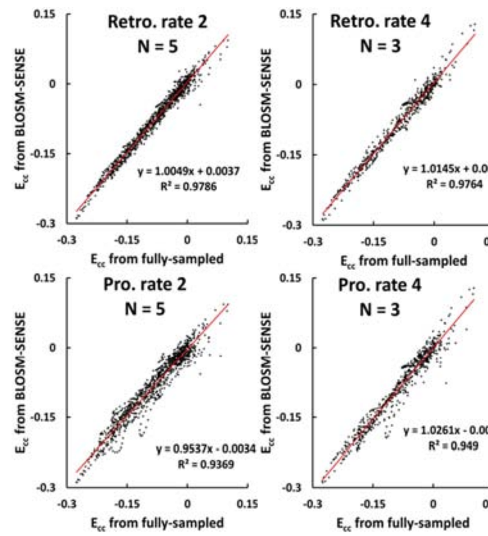

Figure 3. Correlation of segmental E_{cc} from retrospectively undersampled and prospectively accelerated cine DENSE vs. fully-sampled data.

Results: Example fully-sampled, retrospectively undersampled, and prospectively

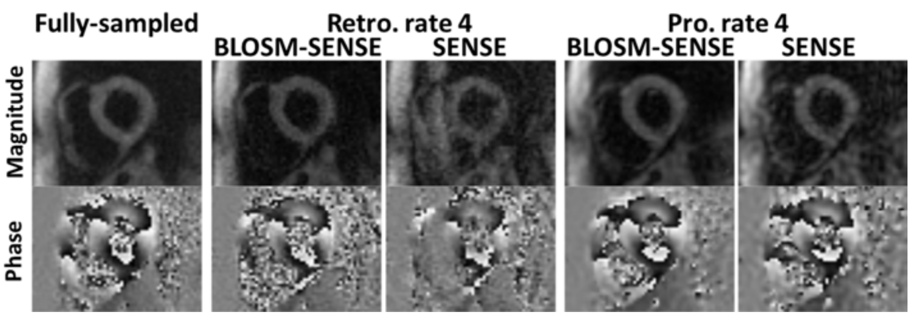

Figure 2. Example end-systolic DENSE images. Magnitude and phase-reconstructed images from fully-sampled, retrospectively undersampled, and prospectively accelerated datasets. BLOSM-SENSE and SENSE reconstructions are shown. BLOSM-SENSE offered high SNR images. For the 5 volunteers, Retro. rate 2 BLOSM-SENSE MSE = 1.5±0.4e-7, SENSE 3.9±0.5e-7; Retro. rate 4 BLOSM-SENSE MSE = 1.5±0.5e-7, SENSE 7.1±1e-7; Also, for the 5 volunteers, fully-sampled SNR = 23.9±4.2, rate 4 BLOSM-SENSE 18.1±7.4, SENSE 6.9±3.1; ANOVA P<0.01 BLOSM-SENSE vs. SENSE).

accelerated magnitude- and phase-reconstructed cine DENSE images are shown in Fig 2. Images reconstructed with BLOSM-SENSE had lower error and higher SNR than using SENSE alone (p<0.01). E_{cc} computed from BLOSM-SENSE-reconstructed undersampled data from all 5 volunteers correlated closely with fully sampled data for both rates 2 and 4, and for both retrospectively and prospectively accelerated data (Fig 3).

Conclusions: Using variable-density spiral acquisitions with golden angle rotations and BLOSM-SENSE reconstruction, accelerated cine DENSE images with two-dimensional in-plane displacement encoding can be acquired in a single breathhold, as short as 8 heartbeats. This represents a significant improvement over prior protocols that used two 14-heartbeats breathholds to acquire equivalent datasets. These methods, when available with rapid online reconstruction, may significantly simplify the clinical use of cine DENSE for high-quality myocardial strain imaging.

References: [1]Chen et al. MRM accepted. [2]Pruessmann et al. MRM 1999;42(5):952-62 [3]Fessler et al. IEEE Trans Sig Proc 2003;51(2):560-74 [4]Spottiswoode et al. IEEE Trans Med Imag 2007;26(1):15-30

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