# SUPPRESSION OF ARTIFACTS IN COMPRESSED SENSING CINE MRI

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**Target audience:** All interested in highly accelerated cine MRI or accurate compressed sensing reconstruction.

**Introduction:** The compressed sensing (CS) technique is useful for accelerating MRI [1,2]. It is suitable for cine MRI because there is a need for reducing the scanning time, and there is a compressible redundancy, especially in the time direction. In these circumstances, a reconstruction algorithm competition - the 2013 ISMRM Challenge - was held [3]. It was aimed to create the most accurate and robust reconstruction algorithm that can be applied to accelerating cardiac dynamic imaging. Sampling patterns in the challenge were roughly divided into two types: undersampled in 1D (2D cine) and 2D (3D cine). We concentrated on suppressing artifacts in 2D cine, which is commonly used in routine protocol. Our algorithm, however, advanced to the final and had a higher rank in overall cases.

The goal of this presentation is to introduce a novel method related to CS and show its efficacy in suppressing artifacts. The method is a part of the algorithm submitted to the ISMRM Challenge. It is applicable to general compressed sensing MRI as well as cine MRI.

**Methods:** Image reconstruction is based on $\ell_1$-ESPIRiT [4,5]. It solves the following optimization problem:

$$\text{minimize}_x\ \text{Joint}\ell_1(\mathbf{\Psi}x),\ \ \text{subject to} \left\|\mathbf{G}x - x\right\| < \varepsilon_1 \wedge \left\|\mathbf{DF}x - y\right\| < \varepsilon_2 \wedge \left\|\mathbf{M}x - \mathbf{F}^{-1}\mathbf{M'}\,y\right\| < \varepsilon_3 \ . \quad (1)$$

Here, $x$ is multi-coil images, and $y$ is acquired data. The function Joint$\ell_1$ is joint $\ell_1$-$\ell_2$–norms. $\Psi$ is a sparsifying transform operator (Wavelet, temporal Fourier and spatial difference). G is a SPIRiT operator, F is a Fourier transform operator, D is a subsampling operator, M is a mean operator, and M' is a selective mean operator. The novelty is the last constraint on mean. The M operator averages images in the time direction, and the M' operator averages acquired data in the time direction only when data exist. Artifacts due to undersampling are significantly eliminated in image $F^{-1}M'y$. The problem is that the inverse of M does not exist. In other words, modification of $x$ in each iteration process cannot be determined uniquely. However, modifying $x$ equally in the time direction works well.

Numerical simulation was performed to evaluate how far artifacts are suppressed and data consistency is maintained. The root-mean-square error (RMSE) between a model and image was used to quantify artifacts, and a healthy volunteer was scanned to confirm the image quality. Data were acquired on a 1.5T MR scanner (ECHELON Vega, Hitachi Medical Corporation, Chiba, Japan) with an 8-channel torso coil with pulse wave gating while the volunteer held his breath. A 2D BASG (balanced steady-state acquisition with rewound gradient echo) was applied, with FOV = 400 × 320 mm, TR/TE = 3.4/1.7 ms, FA = 70°, BW = 287.3 kHz, slice thickness = 10 mm, image matrix = 244 × 218, and temporal resolution of cardiac phases = 34 ms. Data for CS were synthesized from acquired data with an acceleration factor of 2 and three auto calibration signal (ACS) lines. Simulation data were synthesized with an acceleration factor of 5 and 15 ACS lines.

**Results:** Figure 1 shows numerical simulation results. The model consists of a beating heart and the surrounding body (a: end-systole, b: end-diastole). Artifacts occurred with conventional CS (c, d: 1/5 window width) and were suppressed with the proposed method (e, f: 1/5 window width). RMSE changed from 0.016 (conv.) to 0.0053 (proposed), which is 33% of conventional. Figure 2 shows a temporal profile at a point indicated by a small cross in figures 1a and 1b. Artifacts during end-systole were suppressed with the proposed method, while no temporal blurring occurred. Figure 3 shows reconstructed images of the healthy volunteer. The left image is a full sampled reference (a). Artifacts indicated by red arrows occurred with conventional CS (b) and were suppressed with the proposed method (c). Flow artifacts indicated by a blue arrow in the reference image were suppressed with both the conventional and the proposed methods. No image degradation was observed with proposed method.

**Discussion:** The new constraint on mean is different from conventional CS constraints. The dimensions of space where a constraint is described are lower than that of image space. This results in an absence of the inverse and discrepancy toward CS requirements. The possible reason the proposed method suppresses artifacts is that constraints in such a different space with an artifact-free mean image squeeze a solution set effectively.

A result of the M' operator is expected to be almost equal to that of the M operator. Even if there is a difference between the results of M' and M, the difference will dissipate in the time direction. In other words, $\varepsilon_3$ will be small enough. This is the possible reason there is no image degradation.

Suppression of flow artifacts appearing in a reference image is attributable to acquisition acceleration.

**Conclusion:** In conclusion, a novel method that suppresses artifacts in CS cine MRI was proposed. The simulation results show that the proposed method reduces artifacts to 33% without temporal blurring. The scanning results show that artifacts are successfully suppressed without image degradation.

**References:** [1] D. Donoho, IEEE Trans Inf Theory 2006;52;1289-1306. [2] M. Lustig et al., MRM 2007;58;1182-1195. [3] The 2013 ISMRM Challenge. http://www.ismrm.org/challenge. [4] M. Murphy et al., IEEE Trans Med Imag 2012;31;1250-1262. [5] M. Uecker et al., MRM 2014;71;990-1001.

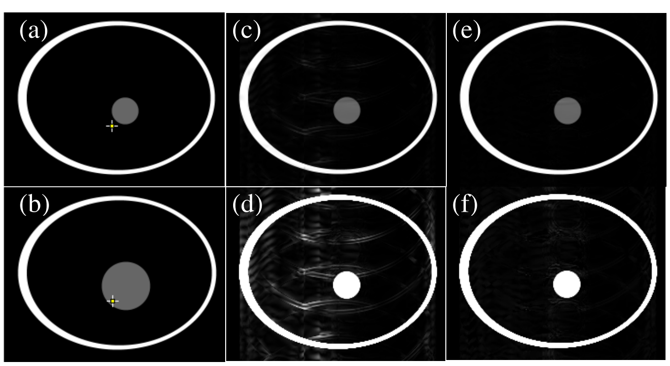


Figure 1. Simulation images. (a) Model at end-systole. (b) Model at end-diastole. (c,d) Conventional. (e,f) Proposed. (d,f) 1/5 window width.

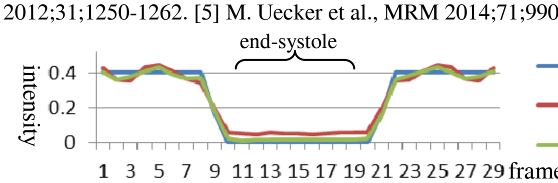


Figure 2. Temporal profile

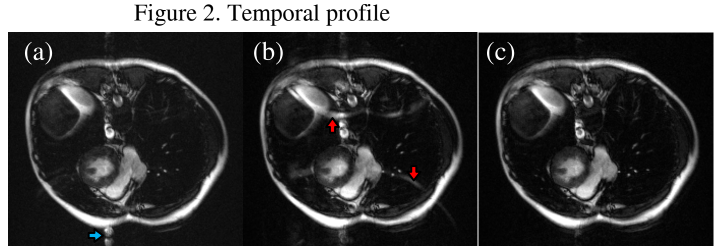


Figure 3. Volunteer images. (a) Reference. (b) Conv. (c) Proposed.