POCS-Enhanced Parallel MRI Correction of MR Image Artifacts

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Introduction: Many MR image artifacts such as motion or *k*-space spike artifacts are caused by corrupted *k*-space samples. Post-acquisition correction of such artifacts can be realized by detecting the erroneous samples and regenerating them. For multicoil data, the strategy may be implemented using parallel MRI (P-MRI) techniques [1,2]. The P-MRI-based artifact correction methods [3-5] rely on redundancy of multicoil MRI data and require *a priori* information about coil sensitivities. Another approach for post-acquisition artifact correction utilizes *a priori* information about the imaged object to realize the same strategy. One prominent example is object support constraint used in a number of the techniques [6,7]. *A priori* information presented in the form of constraints is often applied using Projections Onto Convex Sets (POCS) method, which is efficient in handling many nontrivial constraints in image restoration problems.

In this work, we present a new method for correction of image artifacts caused by corrupted samples in multicoil MRI data. The method is built upon POCS-based method for P-MRI reconstruction (POCSENSE) [8]. It combines advantages of both POCS and P-MRI approaches for more robust error detection and artifact correction than achievable by applying the approaches individually. Additionally, we introduce a new way to improve motion artifact correction using low-resolution phase estimate as a POCS constraint (*smooth-phase* constraint).

Theory: The first stage of our method (error detection) is based on analysis of the subsequent POCSENSE iterates [8] in a way similar to the linear robust techniques [5]. First, a POCSENSE iteration including constraining projections is applied to the initial *k*-space data $m_i(\boldsymbol{k})$ (i=1…N_C, N_C is the number of coils) to update *k*-space estimates $m_i^*(\boldsymbol{k})$. The updated data are more consistent than the original data because of P-MRI data redundancy and POCS constraints used for their evaluation, and may be used to identify erroneous samples. For this purpose, detection maps are formed comparing initial and updated data:

$$d_i(\boldsymbol{k}) = m_i^*(\boldsymbol{k}) - m_i(\boldsymbol{k}), i = 1, ..., N_C . \tag{1}$$

If the initial data had been consistent, the detection maps would contain only noise values. Inconsistent samples are identified as outliers among the background values. On the second stage, the samples are regenerated using a P-MRI technique (Fig. 1).

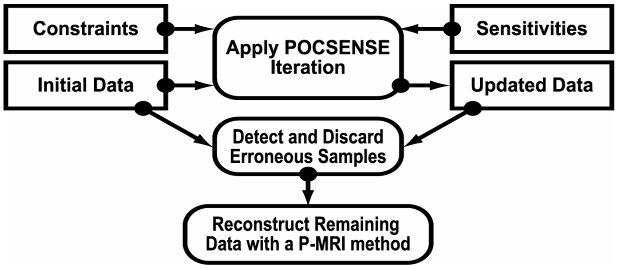

Figure 1. Flow chart of the new method. For iterative (image-based) estimation of coil sensitivities, the procedure is applied repeatedly and coil sensitivities are estimated from refined coil images on each step.

Methods: All imaging experiments were performed on 1.5T GE SIGNA scanner (GE Medical Systems, Milwaukee, WI) using 4-element phase array (N_C=4) and FSE sequence. Phantom object was scanned twice, the object being repositioned between the scans. The data from the second scan were used to simulate motion corrupted lines in the first dataset (total 19 % of lines). One hundred instances of artificially corrupted data were used to evaluate the methods' performance (Tables 1,2). Volunteer was asked to move his head in random fashion during brain scan. For identification of erroneous lines, we used 1-D plot formed by adding magnitudes of detection maps in the readout direction. Peaks were identified by thresholding its second derivative. In addition to object support, we tested smooth-phase constraint. The constraint was obtained from corrupted image at low resolution. The use of such constraint was motivated by the fact that ghosting due to motion often introduces rapidly varying features into image phase. At the same time, the MRI image phase is often of low-frequency content. The phase constraint was applied using corresponding projection [8]. POCSENSE was used for final reconstruction (Fig. 1).

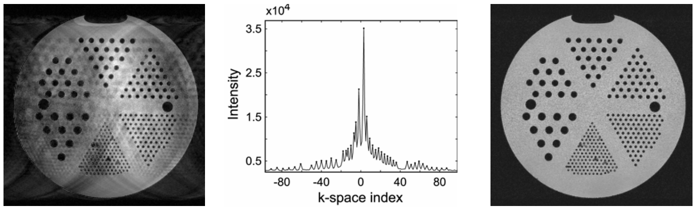

Figure 2. Correction of artificially corrupted phantom data. **From left to right:** corrupted image, detection plot, corrected image.

Results: Table 1 shows the new method's sensitivities for error detection using several constraints, and for two different coil sensitivity estimation approaches. Table 2 compares POCSENSE-based correction with the method proposed in [4], which detects errors comparing multiple *k*-space copies reconstructed by P-MRI from split data. Figure 2 shows results of correction of simulated motion artifact in phantom data. Figure 3 demonstrates correction of real motion in the brain data.

Discussion: The new method for correction of artifacts in multicoil MRI data is highly sensitive to *k*-space inconsistencies (Table 1) and provides improved artifact suppression (Table 2). The effect is achieved by enhancing P-MRI error detection using POCS constraints. POCS constraints such as object support and smooth-phase significantly increase sensitivity of the error detection (Table 1) resulting in improved artifact removal. Table 1 demonstrates that smooth-phase constraint may be used in POCS-based error detection and correction procedures along or instead of object support constraint. Hence, smooth-phase constraint may be especially important, if air background areas are of limited extent, or could not be robustly detected from the corrupted image. The proposed method could be applied to data acquired with P-MRI reduction factor R greater than $N_C/2$ which is the limit for method in [4]. The requirement on the maximal R of the data is that there should be sufficient P-MRI redundancy in the data after removal of corrupted samples. We expect the new method to be useful for correcting other artifacts caused by corrupted *k*-space data.

	A Priori Coil Sensitivities	Image-Based Coil Sensitivities
No Constraints	93.9%	75.5%
Object Support	95.7%	92.6%
Smooth Phase	94.7%	98.9%
Object Support, Smooth Phase	95.9%	99.0%

Table 1. Sensitivity of POCSENSE-based error detection.

	POCSENSE	Multiple *k*-Space Copies
Sensitivity	93.9%	76.4%
Artifact Reduction	6.9	3.2

Table 2. Comparison of POCSENSE-based and "multiple *k*-space copies" methods (a priori coil sensitivities). Artifact reduction is a ratio of RMS errors before and after correction.

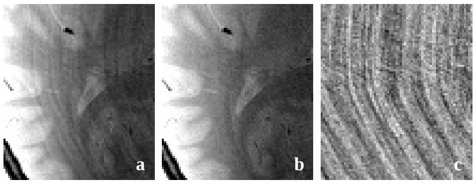

Figure 3. Correction of brain data with motion artifact. **(a)** Initial image, **(b)** refined image, and their difference **(c)**. Note that even subtle ghosting is eliminated.

Acknowledgments:

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References:

[1] Pruessmann K, et al. MRM 1999; 42:952–962.
[2] Sodickson D, et al. MRM1997; 38:591–603.
[3] Kellman P, et al. MRM 2001; 46(2):335-343.
[4] Bydder M, et al. MRM 2002; 47:677-686.
[5] Bydder M. ISMRM 2003; p.482.
[6] Kholmovski EG, et al. MRI 2002; 20:455-462.
[7] Weerasinghe C, et al. IEEE TMI, 1998; 17:310-317.
[8] Samsonov AA, et al. MRM 2004; 52:1397–1406.