# Necessity of sensitivity profile correction in retrospective motion correction

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## INTRODUCTION

Subject motion often results in severe artifacts in MR images. Given motion information (e.g., from external motion detection devices or navigators), the artifacts can be reduced by retrospective correction. Such corrections can be divided into two steps: k-space signal correction and sensitivity map correction. This work presents a study on the effect of the degree of localization of sensitivity maps on motion artifacts, retrospective correction, and the necessity of the sensitivity profile correction step.

## METHODS

Simulations were performed using the 2D Shepp-Logan phantom. K-space data were calculated on a uniform grid of $256 \times 256$ pixel$^2$. The sensitivity maps of an 8-channel receiver coil were approximated using an elliptic Gaussian decay function, $\exp\{-[(x/a)^2 + (y/b)^2]\}$, where $b$ determined the degree of localization of the sensitivity profile and $a = 0.4$ was kept constant. Normally-distributed random translations and rotations were introduced for each phase encoding line. Retrospective motion correction was performed as proposed by Bammer et al. (1). In short, if the object moves while the coil is stationary, the MR signal matrix from coil $\gamma$ will relate to the images as

$$\mathbf{m}_\gamma \;=\; \mathbf{GF}\,\mathrm{diag}(\mathbf{c}^\gamma)\mathbf{v} \;=\; \mathbf{G\Lambda F}\,\mathrm{diag}(\mathbf{\Omega}_{\mathrm{inv}}\mathbf{c}^\gamma)\mathbf{v}_0\,, \qquad\qquad [1]$$

where $\mathbf{G}$: inverse gridding, $\mathbf{F}$: fast Fourier transformation, $\mathbf{c}^\gamma$: sensitivity map of coil $\gamma$, $\mathbf{v}$ and $\mathbf{v}_0$: motion-corrupted and unperturbed images. Motion of the object is described by a matrix $\mathbf{\Omega}$ and $\mathbf{\Omega}_{\mathrm{inv}}$ is its inverse transformation, while $\mathbf{\Lambda}$ is the corresponding transformation rule to $\mathbf{\Omega}$ in k-space. We refer to the two processes of motion correction involving $\mathbf{G\Lambda}$ and $\mathbf{\Omega}_{\mathrm{inv}}\mathbf{c}^\gamma$ as *k-space signal correction* and *sensitivity map correction*, respectively. An iterative non-Cartesian SENSE algorithm (2) was used to reconstruct the images since the corrected k-space data were non-uniformly sampled due to the rotation.

Intuitively, an implementation of both signal and sensitivity map correction as Eq. [1] should yield the best correction. However, the map correction prolongs the computational time of the SENSE reconstruction (particularly when the motion occurs frequently), due to the separation of data into several channels. Therefore, we studied the necessity of the map correction by comparing the results from two different correction strategies: 1) Corr-I: only signal correction with fixed sensitivity maps and 2) Corr-II: both signal and map correction. In this study, we varied the map localization via parameter $b = 0.4, 0.55, 0.7, 0.8,$ and $1.0$ and the translational and rotational motion with standard deviation (SD) of $0.1, 0.5, 1.0, 2.0, 4.0$ pixels or degrees. The artifacts in the image were quantified as percentage error = RMS(image - reference) / RMS(reference) $\times$ 100, where RMS is the root mean square.

## RESULTS

Lower $b$ generated more localized sensitivity maps (compare Fig. 1a-b) and resulted in more artifacts in the motion-corrupted images (Fig. 1c-d) even though the same motion was applied. Signal correction (Corr-I, Fig. 1e-f) evidently reduced the artifacts (e.g., from 60% to 10% for $b = 0.4$, SD = 4 pixels, deg.). Further improvements were obtained after sensitivity map correction (Corr-II, Fig. 1g-h). As shown in Fig. 2, the sensitivity map correction considerably reduced the artifacts when the motion SD was large and the maps were more localized. For small motion or less localized maps, the sensitivity map correction led to only minor improvements. No improvement in the image quality was visible for very small motion (i.e., SD = 0.1 pix, deg. for $b = 0.4$ and SD $\leq$ 0.5 pix, deg. for $b \geq 0.55$). Thus, in this regime, the sensitivity map correction step may be skipped to save computational time.

## DISCUSSION

Motion artifacts originated from both the violation of the Nyquist sampling criterion in some areas of k-space and the mismatch between the sensitivity maps during the signal acquisitions and those assumed during image reconstruction. Although image quality was improved by the signal correction and sensitivity map correction, the remaining artifacts increased with the SD of the motion and the degree of map localization. This may indicate that the errors from the signal undersampling effect and from the map mismatch can not be separately corrected; otherwise, the sensitivity map correction, which can be calculated exactly in these simulations, would result in very similar images for every simulated sensitivity profile for a given motion. Based on the results of this study, abrupt motion with SD of up to 1-2 pixels or degrees (motion in the range of $\pm$ 3 SD) can be well corrected (residual errors less than 1%, see Fig. 2). In conclusion, our results show that although highly-localized sensitivity maps are desirable for high acceleration factors in parallel imaging, they are more problematic for motion artifact correction, due to the potential sensitivity map differences between signal excitations in the presence of motion.

**REFERENCES**
1. Bammer R et al. Magn Reson Med 2007; 57(1):90-102.
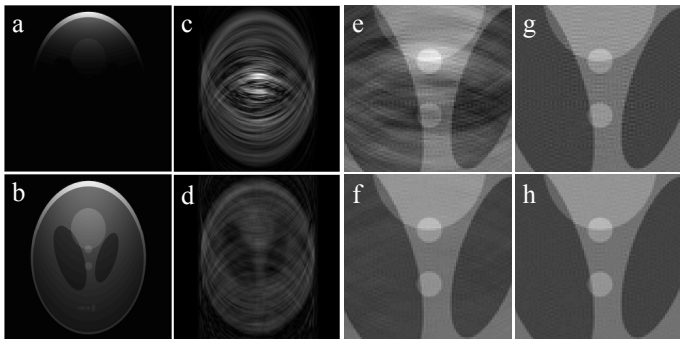2. Pruessmann KP et al. Magn Reson Med 2001; 46(4):638-651.

Fig. 1: Motion artifacts and correction for high (top, $b = 0.4$) and low (bottom, $b = 1.0$) localized sensitivity maps: (a-b) Images from a coil element; (c-d) corrupted images with random motion with SD = 4 pixels, deg.; images after (e-f) signal and (g-h) sensitivity map correction.
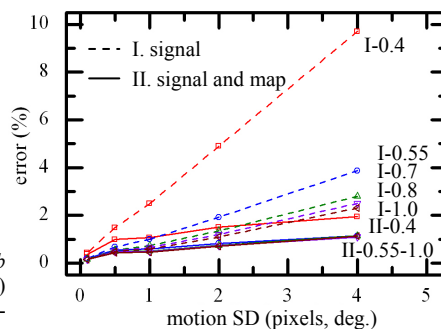


Fig. 2: Residual artifacts quantified by percentage error in corrected images after Corr-I: signal correction (dashed lines) and Corr-II: both signal and map correction (solid lines). The sensitivity map parameter $b$ ($b = 0.4$-$1.0$) is shown next to the curves.