

Combination of prospective and retrospective motion correction for multi-channel MRI

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INTRODUCTION

For high resolution MRI of human brain, subject motion is a major problem which degrades the image quality. Real-time prospective correction (1) is a very promising solution. Based on the motion data, this method updates the coordinates of the imaging volume such that the position and orientation of the subject with respect to the imaging volume remain unchanged for every sequence repetition. Due to noise and latency in an external tracking system, the measured motion data were proposed to be filtered and predicted (2) using a Kalman filter. The method improves the motion data. However, “residual motion” which is the difference of the predicted data and the true subject motion possibly presents and leads to an error of the prospective correction. In this study, motion artifacts after a prospective correction in multi-channel MRI (with spatially inhomogeneous sensitivity maps) were investigated by simulations for different levels of residual motion and different subject motion types. Using both subject motion and residual motion data, a retrospective correction to improve the image quality after the prospective correction is proposed and tested.

METHODS

The Shepp-Logan phantom (matrix 256×256) was used and the coil sensitivity maps of an 8-channel receiver were approximated using a Gaussian decay. We define Ω : subject motion, Ω_{FOV} : motion data used by prospective correction to adjust the imaging volume (FOV), and Ω_{RES} : residual motion ($\Omega_{\text{RES}} = \Omega - \Omega_{\text{FOV}}$). To create a motion corrupted image, all coil sensitivity maps were updated according to the movement of FOV (with Ω_{FOV}) with respect to the stationary coils. The residual motion Ω_{RES} was introduced for each phase encoding line to move the phantom in the FOV.

Retrospective improvement after the prospective correction can be performed using a modified version of the method designed for data without prospective correction (3). With prospective correction, the MR signal matrix from coil γ becomes

$$\mathbf{m}_\gamma = \mathbf{G}\mathbf{A}_{\text{RES}}\mathbf{F} \text{diag}(\Omega_{\text{inv}}\mathbf{c}^\gamma)\mathbf{v}_0. \quad [1]$$

The corrected image \mathbf{v}_0 is obtained after an implementation of two retrospective processes. 1) $\Omega_{\text{inv}}\mathbf{c}^\gamma$: correction of the coil sensitivity map (\mathbf{c}^γ) mismatch by the inversion (Ω_{inv}) of the subject motion and 2) $\mathbf{G}\mathbf{A}_{\text{RES}}$: correction of the k-space signal by the k-space transformation rule (\mathbf{A}_{RES}) corresponding to the residual motion (Ω_{RES}) where \mathbf{G} and \mathbf{F} are inverse gridding and fast Fourier transformation, respectively. Note that the two processes use different motion information (i.e., subject motion and residual motion, respectively).

In this work, abrupt random and smooth motion paths (Fig.1) were considered. For a perfect prospective correction (no residual motion, $\Omega_{\text{RES}} = 0$), the standard deviation (SD_Ω) of subject translation (in pixel) and rotation (in degree) was varied. Imperfect prospective correction was investigated for strong subject motion $\text{SD}_\Omega = 4.0$ pix, deg. for different residual motion $\text{SD}_{\Omega_{\text{RES}}}$. A percentage error = $\text{RMS}(\text{image} - \text{reference}) / \text{RMS}(\text{reference}) \times 100$, where RMS is the root mean square, represents the artifacts level.

RESULTS

As shown in table 1, more accurate prospective correction (less $\text{SD}_{\Omega_{\text{RES}}}$) resulted in better image quality. The artifacts in the images can be further reduced by the proposed retrospective method (Eq. [1]) and the final error decreased with $\text{SD}_{\Omega_{\text{RES}}}$. In addition, abrupt random motion caused more artifacts than smooth motion both before and after the retrospective correction. Importantly, even if prospective correction is perfect ($\text{SD}_{\Omega_{\text{RES}}} = 0$), artifacts still appeared in the images (e.g., Fig. 2a) and the error increased with the subject motion SD_Ω (Table 2). However, these artifacts can be fully corrected in these ideal cases (e.g., Fig. 2b).

DISCUSSION

For multi-channel MRI, subject motion causes changes of k-space signals and coil sensitivity maps in object coordinates. Prospective correction minimizes the error of the k-space signals, unfortunately not the error of the sensitivity maps. Thus, a retrospective correction, in principle, improves the image quality in any case. The error after the retrospective correction increases with the level of residual motion and abrupt motion causes higher error than smooth motion. This originates from increased k-space inconsistency due to the rotation component of the residual motion (leading to density variations in k-space). For an ideal prospective correction, only a sensitivity map mismatch occurs while there is no k-space inconsistency. Therefore, residual artifacts can be retrospectively corrected. Based on the results of this study, improvement by the retrospective correction may be unnoticed for very small subject motion ($\text{SD}_\Omega \sim 0.1$ pix, deg.) if highly accurate prospective correction is applied.

ACKNOWLEDGEMENTS

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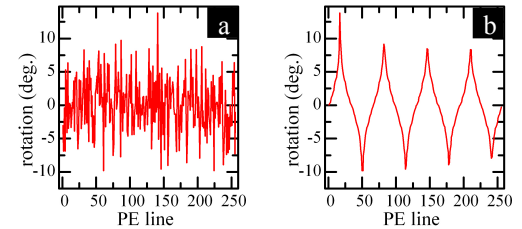


Fig. 1: Graphs of (a) random and (b) smooth rotational motion with the same $\text{SD}_\Omega = 4$ deg.

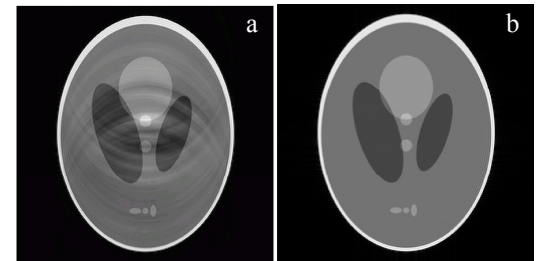


Fig. 2: Images acquired using a perfect prospective correction ($\text{SD}_{\Omega_{\text{RES}}} = 0$): (a) before and (b) after a retrospective correction. Strong abrupt subject motion ($\text{SD}_\Omega = 4$ pix, deg.) was added. See error in Table 1.

Table 1: Artifact level after a prospective correction with different accuracy for strong subject motion $\text{SD}_\Omega = 4.0$ pix, deg: with and without retrospective correction. See corresponding images in Fig. 2.

$\text{SD}_{\Omega_{\text{RES}}}$ (pix, deg.)	error (%)			
	without retro-cor.		with retro-cor.	
	abrupt	smooth	abrupt	smooth
0.0	8.71(a)	1.74	0.01(b)	0.01
0.1	9.44	2.62	0.37	0.24
0.5	18.21	10.05	0.99	0.47
1.0	28.41	17.25	1.02	0.62

Table 2: Artifact level after a perfect prospective correction ($\text{SD}_{\Omega_{\text{RES}}} = 0$) for different subject motion SD_Ω (in pix, deg.).

motion	error (%)				
	$\text{SD}_\Omega = 0.1$	0.5	1.0	2.0	4.0
abrupt	0.22	1.09	2.18	4.36	8.71
smooth	0.04	0.19	0.39	0.82	1.74