Combined prospective-retrospective motion correction for high-resolution brain imaging

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Introduction Prospective motion correction can prevent motion artifacts in MR imaging of the brain [1]. However, for high-resolution imaging, the technique relies on very precise tracking of head motion in a full six degrees of freedom [2]. In most cases, current head tracking systems do not meet these precision requirements. The aim of this work is to relax this restriction and make prospective motion correction practical for high-resolution imaging, even with today's tracking systems. The method proposed is tested in simulations, in MR phantoms and in vivo.

Methods Our combined prospective-retrospective motion correction approach (abbreviated here as 'CPR correction') consists of four stages (Fig. 1). Most motion is corrected prospectively, but, after imaging, all measured tracking data, $\acute{\mathbf{p}}_i$, are processed using a double-sided Kalman filter incorporating knowledge of noise statistics to produce an estimate, $\hat{\mathbf{p}}_i$, of the true object position, $\mathbf{p}_i$, at the time of acquisition of the ith k-space line. An estimate of residual pose (position and orientation) errors is then given by

$$\widehat{\Delta\mathbf{p}}_i = \hat{\mathbf{p}}_i - \acute{\mathbf{p}}_i,$$

where the vector $\mathbf{p}$ contains the three translations and rotations required to represent the pose of a rigid body. Translation errors, estimated as shown above, are then corrected by modifying the phase of the k-space data in accordance with the Fourier shift theorem. Rotation errors, however, result in k-space samples locations that no longer lie on a Cartesian grid. To reconstruct a corrected image, we apply a conjugate gradient reconstruction, similar to that used by Pruessmann et al. [3]. This produces good-quality images in only 5 – 10 iterations.

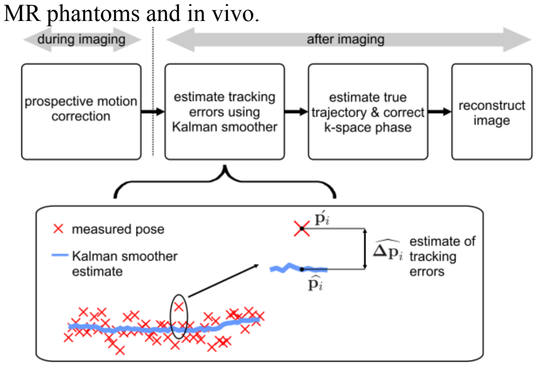

Fig. 1: The combined prospective-retrospective (CPR) correction method.

Shepp-Logan simulations were used to test the CPR correction method with motion restricted to two dimensions. Simulated tracking data (max. translations/rotations were 2 pixels/11 deg.) were corrupted with Gaussian-distributed noise. The imaging process was simulated by using analytical calculation of k-space values, at the exact sample locations required [2]. MR measurements were performed using a 1.5 T Symphony (Siemens, Germany), equipped with a four-channel head coil. Prospective motion correction was applied using a gradient echo sequence modified for the purpose. Navigator data was obtained using the RGR tracking system [4]. In vivo experiments were performed with 3D imaging sequence and with (involuntary) motion in six degrees of freedom. The RGR target was attached to the forehead of the volunteer with double-sided tape. To keep reconstruction times short (seconds), the retrospective part of CPR correction was only applied to translations. This is reasonable for data prospectively corrected with the RGR system, which measures rotations extremely precisely (< 0.01 deg.), but suffers from significant translation noise (≈ 0.4 mm in our current setup).

Results and Discussion Simulation results (Fig. 2) show that prospective correction with noisy tracking data corrects for most motion, but leaves residual ghosting. This is corrected by the CPR approach. Similar results are apparent in MR measurements (not shown) with a moving phantom. Figure 3 shows results of in vivo experiments. Tracking data show that motion of up to 2 mm and 3 deg. occurred during imaging. Although the residual artifacts after prospective correction are slight (Fig. 3a), for high-resolution brain imaging they defeat the purpose of using the technique. Again, the CPR correction approach 'cleans up' these residual artifacts (Fig. 3b). Future work could include knowledge of coil sensitivity profiles, as proposed by Bammer et al., as this can be included into the conjugate gradient reconstruction [5]. It is important, however, to distinguish between genuine motion of the object, where the coil sensitivity profiles will move relative to the prospectively-corrected object (and generate residual artifacts), and apparent motion caused noise in the tracking data, where they will not.

In conclusion, CPR correction is a useful extension to prospective motion correction and makes the technique practical for high-resolution imaging of the brain.

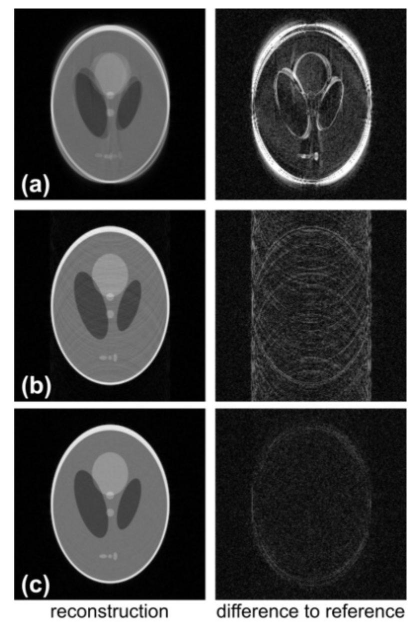

Fig. 2: Simulation results: (a) no correction, (b) prospective motion correction, (c) CPR correction. Residual errors are shown on the right.

References

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[5] Bammer et al., MRM, 2007; 57(1):90-102

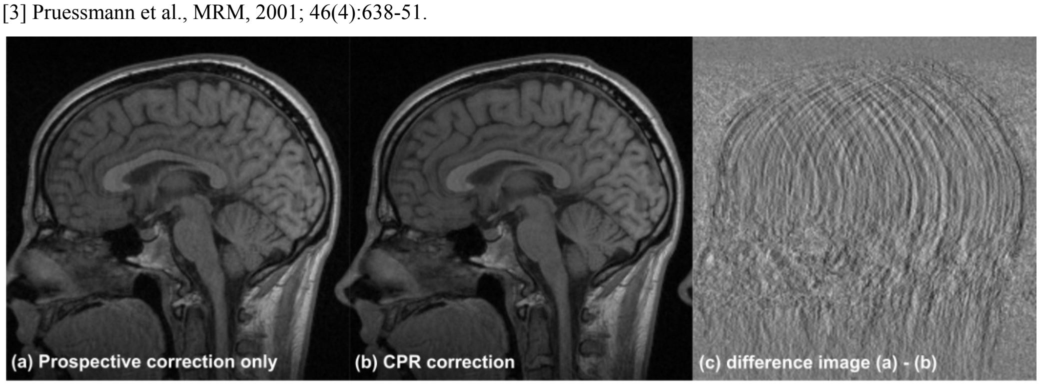

Fig. 3: In vivo results obtained using a modified T1-weighted 3D gradient echo sequence (TE: 4 ms, TR: 13 ms, flip angle: 15 deg., matrix size: 224 × 224 × 60 pixels, FOV: 220 × 220 × 182 mm): (a) prospection motion correction leaves obvious ghosting artifacts; after retrospective correction (b) these are removed. The phase-encode direction is from left to right in the images shown (patient A-P).

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