EXTRACT (Extrapolation and Correlation): A New Ultra-Rapid Motion Correction Technique

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Introduction: Post-processing techniques requiring no additional navigator data have been successfully demonstrated for motion correction in MRI [1-3]. However, high computational costs typically associated with these methods have limited their application. For example, a 2-D translational correction alone could take several minutes to complete [3], and time would be much longer if rotational motion was also considered. This work proposes a new and efficient post-processing technique for motion correction, called k-space EXTRapolation And CorrelaTion (EXTRACT). For each k-space segment, the method first estimates a motion-free reference by extrapolating from a previously motion-corrected region. Motion information is then recovered by correlating the acquired motion-corrupted data with the extrapolated "motionless" data in an efficient manner. A 2-D translational motion correction is typically completed in a few seconds, regardless of the range of the motion.

Theory: For a given k-space data segment S, i.e. several contiguous phase-encoding lines, that is motion-corrupted, if a motion-free reference could be estimated, it is possible to determine the motion (e.g. by correlation [4]). In EXTRACT, this reference is estimated by k-space extrapolation from an adjacent k-space region that is free of motion (**Fig. 1**). For data acquired on a Cartesian grid, the algorithm follows a center-out order, alternating between positive and negative k_y segments. As a result, extrapolation can be carried out on a previously motion-corrected "base" (Fig. 1a) to estimate a reference in the adjacent segment (the rectangular ROI in Fig. 1d). A non-linear image processing technique, originally proposed for image enhancement [5] was adapted for the purpose of k-space extrapolation. An inverse FT of the base data yields a low-resolution magnitude image I_0 (Fig. 1b). Next, the phase coherent harmonics L_0 (Fig. 1c) is generated near edges using the Laplacian operation, where a Gaussian low-pass filtered image is subtracted from the original image. Bounding of L_0 image yields an image with a higher spatial-frequency, on which a Fourier transform can be taken to produce the motion-free extrapolated data (Fig. 1d).

Motion is then estimated by correlating the motion-free extracted reference and the motion-corrupted data. For translational motion, the 2D correlation in image-space could be computed efficiently in k-space by first multiplying the motion-corrupted k-space data with the reference, then taking a Fourier transform of the product [4]. The position of the global maximum on the correlation map then gives the translation that can be used for correction.

Methods: The proposed technique was tested in both a simulation and a phantom experiment. For the former, computer-generated motion trajectories were applied to a previously acquired 512x256 motion-free high-resolution trabecular bone image. For the latter, a 2-D spin-echo sequence with the following parameters was used: 24cm field-of-view (FOV), 5mm thickness, 256×256 matrix, 500 ms TR. A piece-wise constant translational motion was applied manually during the scan. The number of k_y (phase-encoding) lines included in segment S were varied to tradeoff motion resolution with the computation cost. To deal with the reduced SNR near the k-space edge, twice as many line were included when $|k_y|>64$. The image quality improvements following motion correction, on the basis of two image metrics previously studied: entropy [1] and normalized gradient squared (NGS) [2], were compared for EXTRACT and autofocusing [1].

Results and Discussion: The results from the simulation experiment are shown in **Figs. 2** and **3**. The trabecular elements are much more easily delineated following motion correction. The motion trajectory recovered by EXTRACT, which contains multiple sudden shifts as well as continuously varying displacements, closely parallel that of actual simulated motion. In the y-direction, the phase angle $\phi_y = 2\pi k_y \Delta y$, which is used for motion correction, is compared. The mean absolute distance for Δx and Δy (not shown) are 0.65 and 0.41 pixels, respectively. Images from the phantom experiments are shown in **Fig. 4**, demonstrating that the algorithm recovers an image similar to the motion-free control. A comparison of EXTRACT and autofocusing is summarized in **Table 1.** As the temporal resolution increased (smaller S), the effectiveness of EXTRACT improved. While achieving comparable image quality, EXTRACT achieved a speed gain of a factor of approximately 15-25 over autofocusing. Note that for EXTRACT, the image metrics were used only for final image comparison, not for motion correction. It is possible to extend EXTRACT for rotational motion correction. Rotation could be recovered by maximizing the correlation magnitude between the extrapolated data and motion-corrupted data rotated at various angles.

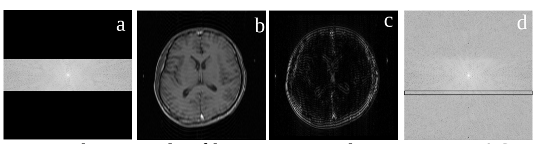

Fig. 1. The principle of k-space extrapolation in EXTRACT. (a): Motionless k-space base. (b) Low resolution I_0 magnitude image. (c) L_0 image. (d) The extrapolated k-space. The rectangle indicates the extrapolated k_y lines.

Conclusion: EXTRACT is a novel, rapid technique for motion compensation. The high computational efficiency makes possible for near real-time motion correction.

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References:

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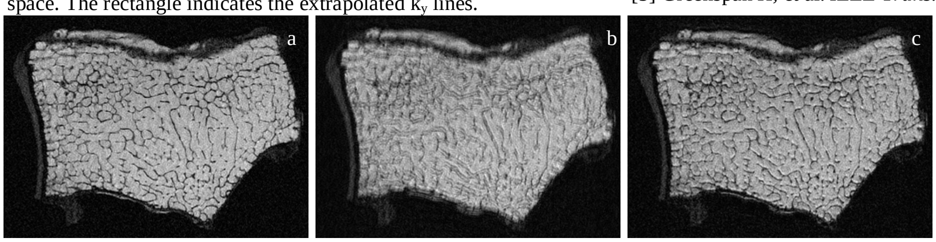

Fig. 2. Motion-free control (a), motion-corrupted (b) and motion-corrected image (c) for the simulation.

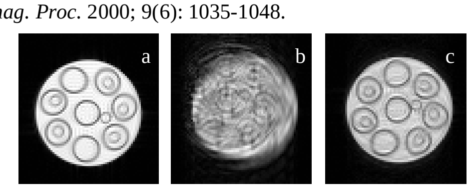

Fig. 4. Motion-free control (a), motion-corrupted (b) and motion-corrected image (c) in the phantom experiment.

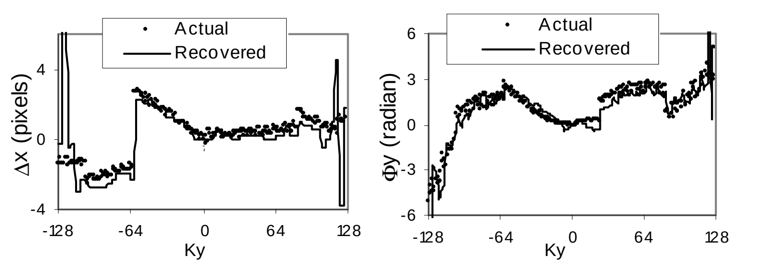

Fig. 3. Comparison of recovered and actual simulated motion for images shown in Fig. 2.

Table 1. Comparison of correction efficacy and computation time of EXTRACT and autofocusing.

Experiment	Correction algorithm	metric improvement		Time (seconds)	No. of k_y lines in segment S
		Entropy	NGS		
Simulation	Autofocusing	64.0%	116.4%	236	4/8
	EXTRACT	58.6%	88.0%	9	4/8
Phantom	Autofocusing	10.2%	56.1%	128	4/8
	EXTRACT	17.3%	59.8%	7	2/4
		40.6%	63.8%	14	1/2