Image-based ghost reduction of amplitude discontinuities in k-space with projections onto convex sets (POCS)

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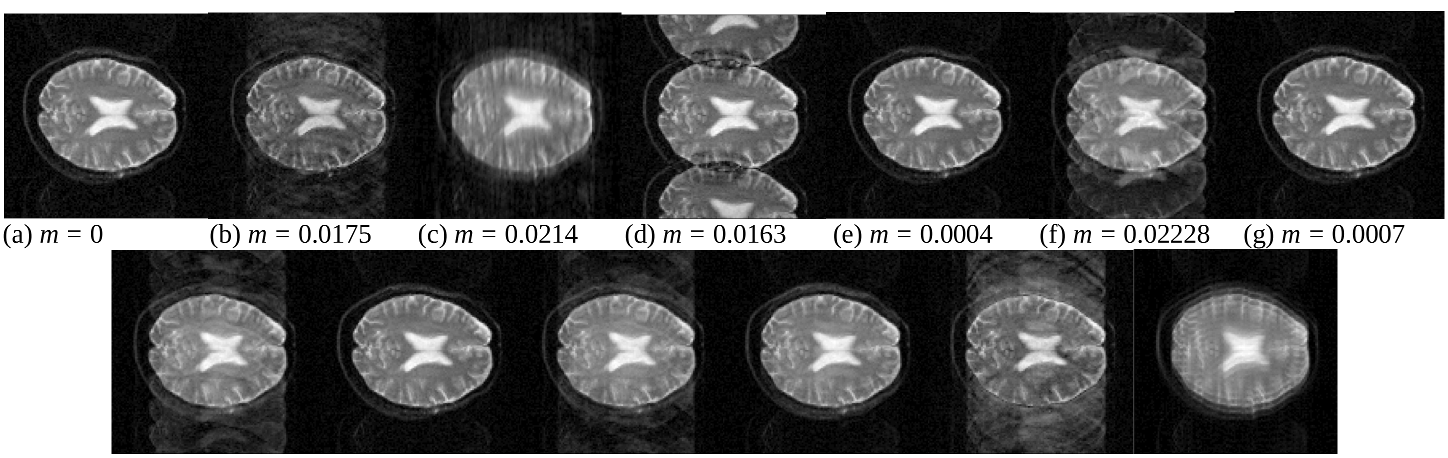
Introduction: Ghosting in an image is often caused by amplitude discontinuities in k-space. For example, this might occur in interleaved EPI due to insufficient T1 recovery between interleaves [1], or in FSE imaging due to T2 decay between echoes [2]. Solutions to these have included: adjustment of flip angle [1], changing phase-encode order to redistribute ghosts [2,3], and use of a reference scan [4]. Projections onto convex sets (POCS) has been used to replace reference scans where phase correction is necessary [5]. This work investigates by simulations the effectiveness of POCS to correct for amplitude discontinuities.

Method: The POCS algorithm takes a k-space with amplitude discontinuities and iterates the following steps until convergence: (i) reconstruct ghosted image (ii) mask ghosted image with a region of support (ROS) to set image outside parent to zero (iii) Fourier transform masked image to give a "model k-space" (iv) set the amplitude of corrupted k-space to that of "model k-space". We can impose additional constraints by using *a priori* knowledge to correlate the amplitude variations. We use the model which assumes that the amplitude of echoes in each interleaf differs from those of other interleaves by a constant fraction only.

We performed simulations on a test axial human brain image (see Fig 1a), acquired with a spin-echo EPI sequence with 128 phase encode lines. To test the algorithm without *a priori* constraints, each phase encode line in raw k-space was multiplied by a random fraction to generate the ghosted image (Fig 1b). The algorithm was run until the change in consecutive amplitude corrections was < 0.1%. The mean absolute difference between final and test image within the ROS was used as a metric. To test the algorithm under model constraints, all lines belonging to the same interleaf were multiplied by the same randomly chosen fraction. The highest intensity line corresponding to a particular interleaf was used to find the normalisation factor for all other lines in that interleaf. The ROS and other measures were unchanged. Simulations for 2, 4, 8, 16, and 32 interleaves were performed.

Results and Discussion: Fig. 1(c) shows the resulting severely corrupted image after correction without constraints. With model constraints, Figs. 1(d) to 1(m) show images before and after correction, with simulated number of interleaves n = 2, 4, 8, 16, 32. The algorithm is able to correct for low numbers of interleaves only, up to approximately n = 8. With large n, the ghosting outside the ROS is suppressed, but the parent image becomes very blurred with loss of detail. In general, the number of iterations before convergence increased with increasing number of degrees of freedom, ranging from around 5 iterations for 2 interleaves to over 50 iterations with 32 interleaves.



(a) m = 0 (b) m = 0.0175 (c) m = 0.0214 (d) m = 0.0163 (e) m = 0.0004 (f) m = 0.02228 (g) m = 0.0007

(h) m = 0.0177 (i) m = 0.0030 (j) m = 0.0160 (k) m = 0.0115 (l) m = 0.0287 (m) m = 0.0205

Figure 1. (a) deghosted slice for simulation. Each following pair of images shows simulated ghosting and result of POCS correction. m = mean absolute difference between corrected and test image. (b),(c) no model constraints;(d),(e) 2-interleaves; (f),(g) 4-interleaves; (h),(i) 8-interleaves; (j),(k) 16-interleaves; (l),(m) 32-interleaves.

Conclusion: In order for the POCS algorithm to be successful, an *a priori model* is required to reduce the number of degrees of freedom to approximately 7, equivalent to an 8 interleaved EPI or 8-echo train length FSE image.

References: [1] McKinnon GC, MRM 1993;30:609-616. [2] Keller PJ et al, MRM 1995;33:838-842. [3] Kholmovski EG et al, JMRI 2000;11:549-558 [4] Zhou X et al, JMRI 1993;3:803-807 [5] Lee KJ et al, MRM 2002;47:812-817.