Density Compensation for TrueFISP Blade Imaging in the Steady State (TrueBLISS)

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Introduction: Rotating blade trajectories, such as RUKSE[1] and PROPELLER/BLADE[2] have been proposed. For these non-Cartesian trajectories, modulation in the gridded K-space can arise at the overlap between blades, which would ideally be addressed by the Density Compensation Function (DCF). The Jackson[3] method in addition to being computationally intensive can be shown to faithfully reproduce this modulation. This work proposes two alternatives to the Jackson method for blade imaging: Amateur Hack (AH) and Iterative Grid / De-Grid (IGDeG). The results obtained with a synthetic phantom and in the abdomen of an asymptomatic volunteer using a TrueFISP Blade Imaging (TrueBLISS) sequence demonstrate that: IGDeG yields superior image quality to either the AH or Jackson method; and, the AH and IGDeG methods compute a DCF 6000 and 30 times faster in Matlab than the Jackson method, respectively.

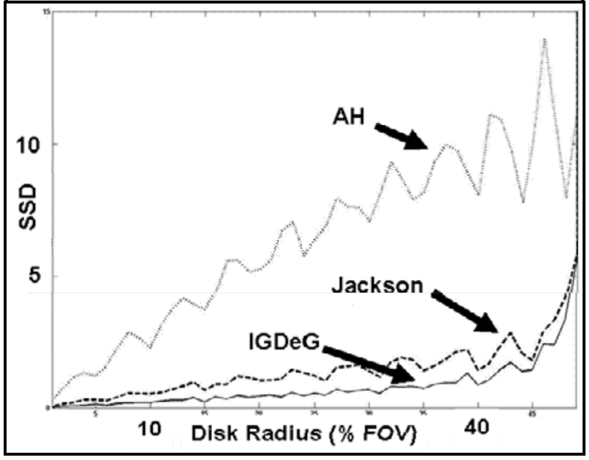
$$\Psi\left(k_r\right)=\frac{-1+I_0\left(\beta\sqrt{1-\left(\frac{k_r}{w/2}\right)^2}\right)}{-1+I_0\left(\beta\right)} \qquad [1]$$

Table 1: Shaping parameter (β) values and image domain filter characteristics

β	HWHM (samples)	HWTM (% of w/2)	δ (% of FOV)	Δ
9	**1.4**	**68.6**	**4.5**	**-3.5**
10	**1.3**	**65.7**	**5**	**-4.0**
20	**0.9**	**48.6**	**9.3**	**-7.7**
30	**0.8**	**40.0**	**13.8**	**-12.1**
13.2	**1.1**	**57.1**	**6.3**	**-4.9**

Materials and Methods: A rotating blade trajectory and uniform disk phantoms (radius 1-50% of the FOV) were simulated for reconstruction in Matlab (Mathworks. Nattick, MA). The blade parameters were: 256 samples per view, 21 views per blade and 19 blades per acquisition with angular spacing of 9.5°. The actual implementation of the sequence was developed for a clinical Siemens 1.5T Sonata imager (Siemens Medical Solutions, Erlangen, Germany) using a TrueFISP Blade Imaging in the Steady State (TrueBLISS) pulse sequence. The same blade parameters were selected to collect an axial slice in the abdomen of an asymptomatic volunteer for offline reconstruction. A circularly symmetric convolution filter [Eqn. 1] of diameter w = 7 samples was used as needed in the DCF estimations and for final gridding to a 512^2 matrix. Shaping parameter (β) for the filter was constrained to satisfy certain conditions: (1) Half-width half-maximum (HWHM) > 1 sample to reduce residual structure in the modulation transfer function (MTF); (2) Half-width tenth-maximum (HWTM) > 50% of filter radius to justify the computational expense for using a wider window; and, (3) Change in log magnitude (Δ) of the first sidelobe relative to the peak < -3 (10x oversampled spatial representation of the filter as in Figure 1) to limit the impact of filter sidelobes. Distance to the first sidelobe (δ) was also reported for selected β in Table 1. For β = 13.2 and an ideal trajectory, the DCF was estimated with the Jackson, Amateur Hack (AH) and Iterative Grid / De-Grid (IGDeG) methods. Figure 2 shows the IGDeG concept, which is similar to that of Pipe[4]. The time to compute each DCF in seconds in Matlab was recorded. Each method was used to reconstruct a disk phantom, where sum of squared difference (SSD) from a planar disk was computed. The DCF variants were applied to the volunteer data.

Figure 3: SSD vs. Object radius



Results: The Jackson, IGDeG and AH method required 5384, 174, and 0.875 seconds in Matlab to compute the requisite DCF. Relative to AH, IGDeG and Jackson attained their estimate 200 and 6000 times slower. Figure 3 shows the sum of squared difference (SSD) versus simulated object size. Figure 4 shows the MTF for each DCF method. Note the residual structure in the Jackson (Fig. 4a) and AH (Fig. 4b) MTF is absent in the IGDeG result (Fig. 4c). Figure 5 shows the results from the human volunteer.

Discussion: Despite the design constraints, the Jackson method yielded structure in the MTF at the blade overlaps (Fig. 4a), which is reduced by using the Iterative Grid / De-Grid method. Although the SSD from the ideal object for Amateur Hack is large in comparison to the other methods (Fig. 3), results (Fig. 5b) are comparable to the other methods (Fig 5a,c) in abdominal imaging. Vast time savings and simplicity make Amateur Hack attractive for real-time DCF estimation (e.g. during an interventional procedure). For progressively larger objects, spatial information concentrates at the center of K-space, which puts a premium on a uniform MTF for low spatial frequencies. This work confirms for TrueBLISS that Amateur Hack is a rapid alternative to the Jackson method, but Iterative Grid / De-Grid yields superior results.

References: 1. Busch, M. et al. JMRI 1998. 8(4):944-954. 2. Pipe, JG. MRM 1999. 42(5):963-969. 3. Jackson, JI. IEEE TransMedImag 1991. 10(3):473-478 4. Pipe, JG. and Menon,P. MRM 1999. 41(1):179-186.

Figure 1: Log magnitude of image domain representation of the filter for β = 13.2. The first sidelobe appears at 6.3% of the FOV with change in log magnitude of -4.9 relative to the peak of the central lobe.

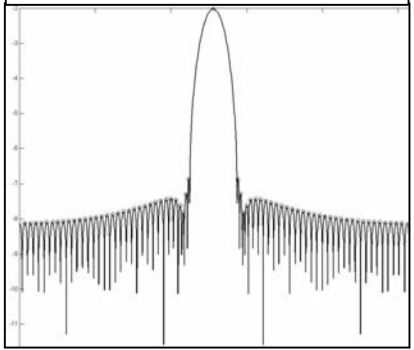


Figure 2: Iterative Grid / De-Grid (IGDeG) Density Compensation. Beginning with “ones” for an initial DCF, five iteration were run for τ = 0.25.

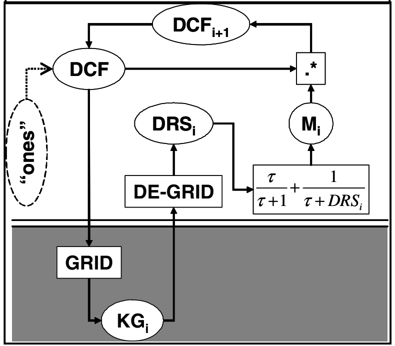


Figure 4: Gridded a) Jackson, b) AH, and c) IGDeG DCF.

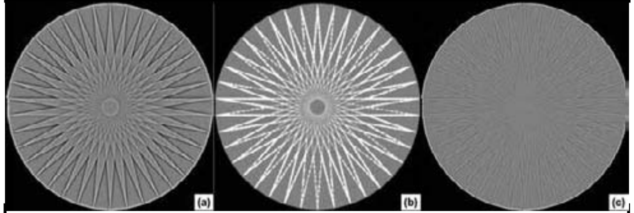


Figure 5: Volunteer image using a) Jackson, b) AH, and c) IGDeG