Channel compression for BLADE

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Introduction: PROPELLER MRI [1] has significant advantages over segmented Cartesian MRI in the presence of motion or flow. Reconstruction times are, however, longer and increase with the number of receiver channels in our PROPELLER implementation (BLADE). This is a problem if novel coils with 32 elements or more are used. In this abstract, we will discuss channel compression techniques to reduce BLADE reconstruction times.

Methods: Fig. 1 shows a schematic illustration of the processing of a single blade.

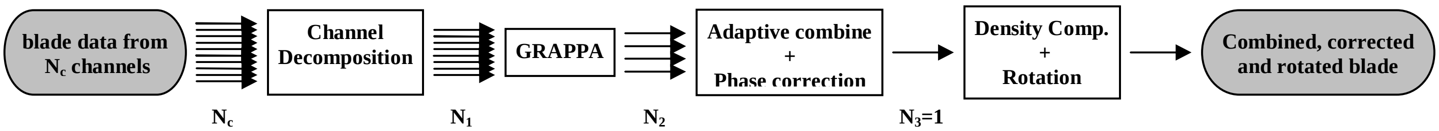


Fig. 1: Processing of a single blade. Optional motion detection and translational correction is done post "Adaptive Combine" and are not shown

Each blade is compressed separately. First singular value decomposition (SVD) is used to decompose the N_c receiver channels to N_1 new virtual channels ($N_1 \leq N_c$) [2]. If GRAPPA [3] is used, the number of channels interpolated by GRAPPA (N_2) is chosen to be smaller than the number of channels used for the interpolation (N_1). The remaining channels can also be combined in image space to one remaining channel using "Adaptive combine" [4]. The remainder of the reconstruction procedure is unchanged. Specific features of the procedure include:

Channel decomposition: M_s samples s_j from the center of the blade are sorted in a M_sxN_c signal matrix A and the SVD of the matrix is calculated:

$$s_j(n) = A(n,j) = \sum_{i=1}^{N_c} \lambda_i \, u_i(n) v_i(j)^*, \quad 1 \leq n \leq M_s, 1 \leq j \leq N_c, \lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_{N_c} \geq 0 \quad (1)$$

The right singular vectors $\vec{v}_i$ associated with the N_1 largest singular values λ_i are used to calculate N_1 new channels:

$$\tilde{u}_k(m) = \lambda_k u_k(m) = \sum_{j=1}^{N_c} s_j(m) v_k(j), \quad 1 \leq k \leq N_1 \quad (2)$$

The number of samples M_s in (1) is chosen to be eight times the number of receiver channels N_c. (2) is evaluated for all measured samples of the blade.

GRAPPA: GRAPPA estimates each missing sample as a linear combination of the measured data from all channels (here N_1) in a k-space neighborhood of the sample. Normally a channel-by-channel reconstruction is used, in which the missing data of all input channels are estimated. Here only the channels associated with the N_2 largest singular values ($N_2 \leq N_1$) are completed, while all input channels are used in the linear sum. The linear weights needed for GRAPPA are estimated from a few extra, sufficiently sampled, ACS lines in the center of the blade.

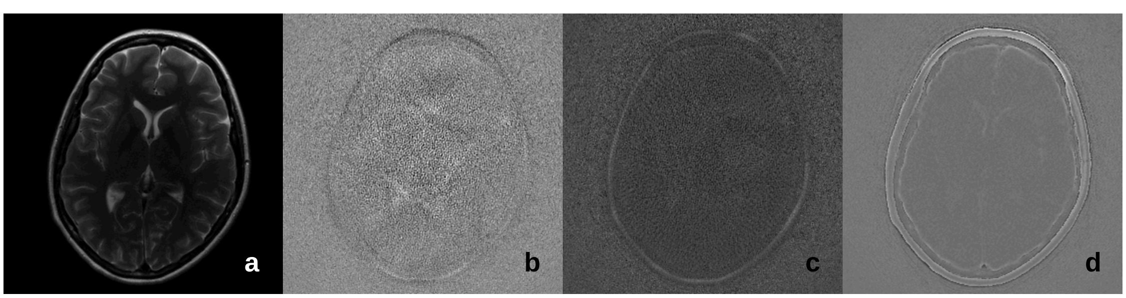
Adaptive combine: The data of the N_2 remaining channels are transformed in image space during phase correction. As an option, the channels are combined to one complex image using the eigenvector associated with the largest eigenvalue of the local channel correlation matrix [4].

Rotation: BLADE implements rotations by successive shearing operations instead of "Gridding" [5].

Results and conclusion: Test data were collected from a volunteer on a MAGNETOM Trio using a 32-channel receive coil (Matrix size 320, ETL 33, GRAPPA factor 4 with 6 extra ACS lines per blade, 108 lines per blade). Reconstruction times per blade for several values of N_1, N_2, and N_3 can be found in Table 1. The times were measured online in single threaded mode using an imager with AMD Opteron 875 processors. For these parameter settings the reconstructed images are undistinguishable to the human eye. If the number of channels before GRAPPA is reduced to 16 or less the difference image reveals some residual GRAPPA artifacts (Fig.1b). These artifacts can be avoided by increasing N_1. Decreasing N_2 partly compensates for the extra time (Fig.1c). The acquisition time per blade is approximately 250 ms (~2xTE). A processing speed per blade of 1000 ms and the 4 AMD Opteron 2216 CPUs of the latest imager therefore guarantee that the blade-wise operations (listed in Table 1) are completed during the acquisition. The non-blade wise operations, which cannot be started before the end of the scan (e.g. final Fourier Transform), are comparatively fast. Adaptive combine or any other complex combine algorithm allows a further reduction of reconstruction times if numerical extensive operations are performed post GRAPPA (e.g. motion detection).

$N_1/N_2/N_3$	Channel decomp.	GRAPPA	Adaptive comb. and/or Phase corr.	Rotation	Total	Mean error
32/32/32	0	1437 ms	444 ms	385 ms	2265 ms	0.0±0.0%
16/16/16	233 ms	326 ms	226 ms	195 ms	979 ms	2.0±2.1%
24/12/12	348 ms	403 ms	168 ms	147 ms	1066 ms	0.8±1.1%
24/12/1	350 ms	402 ms	234 ms	17 ms	1002 ms	1.5±3.5%

Table 1: Measured reconstruction times. Mean errors are measured in a central 128x128 window relative to the $N_1=N_2=N_3=32$ image



References:

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MRM 47:1202-1210 (2002)

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[5] US Patent Application
Pub. No 2006-0264735

Fig. 2: a. 32-channel BLADE reference image ($N_1=N_2=N_3=32$); b. difference image, if 16 channels are used past decomposition ($N_1=N_2=N_3=16$); c. difference image, if 24/12 channels are used as GRAPPA input and output, respectively ($N_1/N_2/N_3=24/12/12$); d. difference image, if adaptive combine is used ($N_1/N_2/N_3=24/12/1$)