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# New Approach for Data Acquisition and Image Reconstruction in Parallel Magnetic Resonance Imaging

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## Abstract

In this study, we propose a novel data acquisition and image reconstruction method for parallel magnetic resonance imaging (MRI). The proposed method improves the GRAPPA algorithm by simultaneously collecting data using the body coil in addition to localized surface coils. The body coil data is included in the GRAPPA reconstruction as an additional coil. The reconstructed body coil image shows greater uniformity over the field of view than the conventional sum-of-squares (SoS) reconstruction that is conventionally used with GRAPPA. The body coil image can also be used to correct for spatial inhomogeneity in the SoS image. The algorithm has been tested using numerical and real MRI phantom data.

## 1. Introduction

Parallel magnetic resonance imaging (MRI) increases image acquisition speed by taking advantage of multiple surface radio-frequency (RF) coils [1-8]. In conventional MRI, the full k-space data required for a certain field of view (FOV) and resolution are collected, whereas in parallel imaging the k-space is subsampled by a certain factor R. Consequently, individual aliased images are obtained for every coil. These images are either unfolded in the image domain to yield the final image or the missed k-space lines are reconstructed using a priori information from the spatially varying coil sensitivities. The quality of the image reconstructed is an essential criterion for the success of parallel imaging. Many parallel imaging reconstruction techniques have been proposed. Examples include SENSE, SMASH, GRAPPA and their derivations [1-8]. These methods can be divided into image domain and k-space methods. The k-space methods when used with the additional acquired auto-calibration data are very powerful in cases where determination of the coil sensitivity is difficult or is time varying. Among all these reconstruction methods, GRAPPA (Generalized Auto calibrating Partially Parallel. Acquisitions) has been of most interest due to the improved performance in reconstructing high resolution images and overcoming the limitations in previous techniques like SMASH and VD-Auto-SMASH [5-8]. GRAPPA represents a more generalized implementation of the VD-AUTO-SMASH approach [8]. Although both techniques share the same acquisition scheme, they differ significantly in the way reconstruction of missing k-space lines is performed. One basic difference is that the component coil signals are fit to just a single component coil auto-calibration signal (ACS), not a composite signal, thereby deriving the linear weights to reconstruct missing k-space lines of each component coil. This process is shown in Fig. 1. Data acquired in each coil of the array (black circles) are fit to the ACS line (gray circles). However, as can be seen, data from multiple lines from all coils are used to fit an ACS line in a single coil, in this case an ACS line from coil 4. The fit gives the weights which can then be used to generate the missing lines from that coil. Once all of the lines are reconstructed for all coils, a Fourier transform can be used to generate individual coil images. The full set of images can then be combined using a normal sum of squares (SoS) reconstruction.

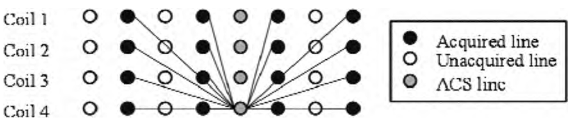

Fig. 1 Schematic description of GRAPPA with an acceleration factor R = 2.

Reconstructing data in coil j at a line (ky-mΔky) offset from the normally acquired data using a blockwise reconstruction can be represented by:

$$S_j(k_y - m\Delta k_y) = \sum_{l=1}^{N}\sum_{b=0}^{N_b-1} n(j,b,l,m)\, S_l(k_y - bR\Delta k_y) \quad , \qquad (1)$$

where Sj(ky) is the signal in coil j at line ky. In this case, Nb lines which are separated by RΔky are combined using the weights n(j,b,l,m) to form each line, corresponding to a reduction factor R. The coefficients n(j,b,l,m) represent the weights used in this linear combination, the index l counts through the Individual coils, while the index b counts through the individual reconstruction blocks. This process is repeated for each coil in the array, resulting in L uncombined coil images which can then be combined using a conventional sum of squares reconstruction or any other optimum array combination [9].In spite the success of the GRAPPA technique, the sum of squares step carried on as the final step of reconstruction can not guarantee uniformity over the field of view. In general, accurate knowledge of the coil sensitivity is required in order to produce uniform-intensity images. In this work we present an acquisition and reconstruction scheme that substantially improves the current GRAPPA reconstruction technique by utilizing the additional data collected from the uniform body coil.

## 2. Methodology

Simultaneous acquisition of reduced k-space data sets from both the body coil and the surface coil array is proposed so that a uniformly-weighted image reconstruction can be achieved. The additional body coil is included in the GRAPPA reconstruction process as a regular surface coil, except that this special coil has a uniform sensitivity over the FOV. This approach is illustrated in Fig. 2. The process of individual coil estimation is carried on using GRAPPA according to (1). After the reconstruction of every coil image, the body coil image among all images has uniform sensitivity and can be regarded as the final reconstruction (R1 in Fig. 3). Unfortunately, this body coil image may suffer from lower SNR because the coil is far away from the imaging volume. It may also suffer from reconstruction artifacts during GRAPPA reconstruction for the same reason. Therefore, the sum of squares reconstruction of all images generated from GRAPPA could be more interesting since the resulting image will have better SNR, lower artifact level and better uniformity (R2 in Fig. 3). Alternatively, a SoS reconstruction of only the surface coils can be compensated for non-uniformity by a pixel by pixel comparison to the body coil image to assure a uniform sensitivities distribution in the final image (R3 in Fig. 3). A procedure for intensity correction is shown in Fig. 4. Simulation is performed using the numerical Shepp-Logan (SL) phantom [10] and 6 surface coils profiles calculated using the Biot-Savart law for circular loop coils. A 128x128 SL image is multiplied with the sensitivity of the 6 coil, Fourier transformed (FT) to obtain a set of six full k-space data sets. A seventh data set is obtained by taking the FT of the SL image directly to simulate a body coil acquisition. The seven data sets are then subsampled with a factor of R = 2. A set of 32 lines at the center of k-space is also retained for GRAPPA training to determine the filter coefficients. Image Reconstruction is performed as described above. For comparison, conventional GRAPPA reconstruction is applied to the six surface coils and taking the sum-of-squares. The described reconstruction is applied to a real MR phantom acquired with a gradient echo sequence on a Philips 3T Achieva system. Because the system does not allow simultaneous receive of signals from the surface coil array and the body coil, two experiments are performed sequentially using the cardiac coil array with six elements and the body coil. The scan parameters were TR/TE=11/2.7 ms, FOV = 40x40 cm, slice thickness = 5 mm, matrix size=448x448.

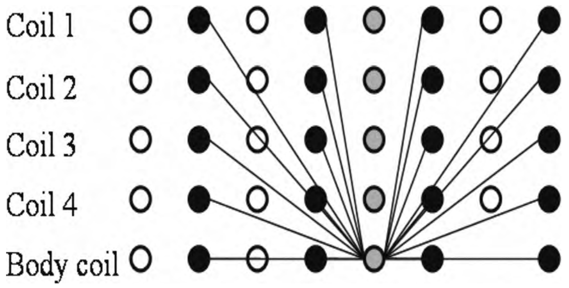

Fig. 2. GRAPPA reconstruction with the additional body coil.

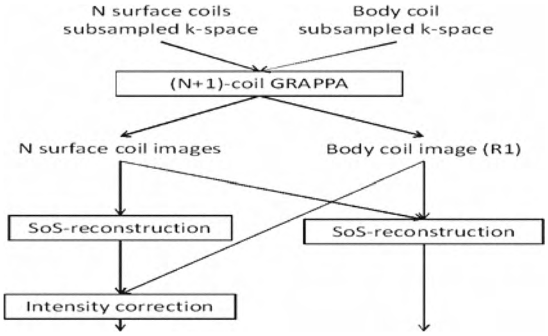

Fig. 3. The modified reconstruction method with the body coil. Possible reconstruction options are marked with R1, R2, and R3.

Fig. 5 shows the results of the simulated SL experiment. noticeable intensity nonuniformity, especially when compared to the body coil image reconstructed using the proposed methods (Fig. 5B). The intensity correction obtained by dividing smoothed version of both images is shown in Fig 5C. The corrected image obtained by multiplying the images in (A) and (C) is shown in Fig. 5D where better uniformity is evident, although some blurring of edges is noticed. The results of applying the proposed method to real MR phantom are shown in Fig. 6. The GRAPPA-reconstructed body coil image (Fig. 6B) shows excellent uniformity but lower SNR than the GRAPPA SoS image (Fig. 6A). The body coil image shows some residual artifact from GRAPPA that could be due to the lower SNR and the higher g-factor [2] in the middle of the image. The intensity-corrected image is shown in Fig. 6D using the correction in Fig. 6C.

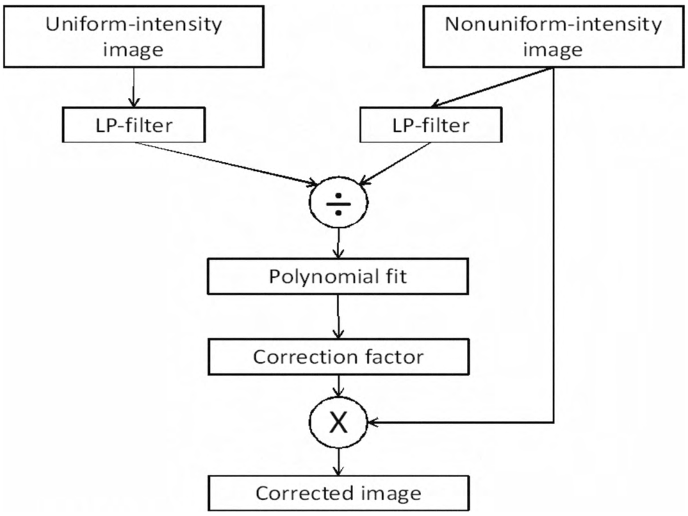

Fig. 4. A possible intensity correction procedure using the uniform intensity image. LP-filter is low-pass filter.

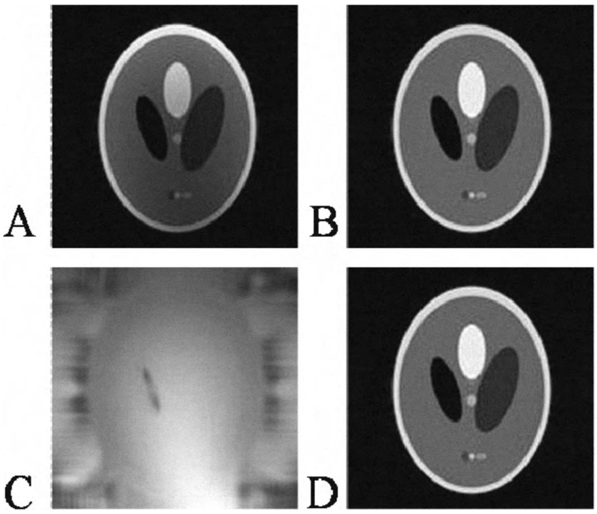

Fig. 5. (A) The sum-of-squares reconstruction of GRAPPA. (B) The body coil image using GRAPPA reconstruction. (C) The correction function obtained by dividing smoothed versions of (A) and (B). (D) The intensity-corrected sum-of-squares image.

## 4. Discussion

The SL results in Fig. 5 shows that uniform intensity is possible if a body coil is incorporated in the acquisition and reconstruction phases of a parallel imaging pipeline. An intensity correction is also possible using the body coil image. Similar results are obtained from real MR scans of a physical phantom. A small residual artifact is noticed in the GRAPPA-reconstructed body coil image. This artifact may be due to the high g-factor in the middle of the image that manifest the lower SNR of the body coil signal. Nevertheless,the uniformity of the body coil image may be in specific situations very important like in phase contrast [11] or strain encoded MRI [12]. The benefit of the uniformity of the body coil and the high SNR of localized surface coils can be traded off in a SoS reconstruction of the whole coil data as shown in Fig. 7.

## 5. Conclusion

We proposed a new method for parallel imaging acquisition and reconstruction that improves the current GRAPPA technique in terms of image uniformity over the entire FOV. By overcoming the current hardware limitation in MRI systems for simulations acquisition, the proposed method will enable improved image quality in parallel imaging.

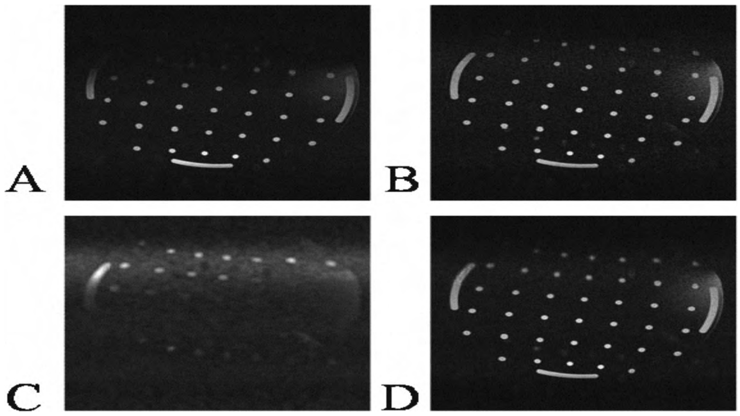

Fig. 6. (A) The sum-of-squares reconstruction of GRAPPA. (B) The body coil image using GRAPPA reconstruction. (C) The correction function obtained by dividing smoothed versions of (A) and (B). (D) The intensity-corrected sum-of-squares image.

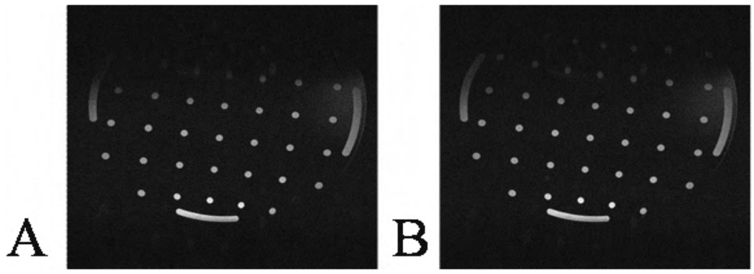

Fig. 7. (A) The sum-of-squares reconstruction of GRAPPA using only surface coils. (B) The sum-of-squares reconstruction of GRAPPA using both the surface coils and the body coil.

## 6. Acknowledgment

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