Boosting image quality by automatic low SNR channel detection and its removal in k-space

C. Ros[1], J. Sedlacik[2], N. C. Daw[3], R. Loeffler[2], J. R. Reichenbach[1], and C. M. Hillenbrand[2]

[1]Medical Physics Group, Institute for Diagnostic and Interventional Radiology, Friedrich Schiller University, Jena, Germany, [2]Department of Radiological Sciences, St. Jude Children's Research Hospital, Memphis, Tennessee, United States, [3]Department of Oncology, St. Jude Children's Research Hospital, Memphis, Tennessee, United States

Introduction: Phased array coils with a large number of coil elements and receiver channels are commonly used to improve the Signal-to-Noise Ratio (SNR) [1] and to reduce the acquisition time by exploiting partial parallel acquisition techniques [2]. Large array coils are also used to cover an extended field of view without the need for switching between various coils and coil elements. However, if an array coil with a large number of elements is applied, some of the coil elements may be located too far away from the actual measurement volume and barely detect any signal. Automated system adjustment routines may then improperly increase the gain factor for these non-contributing channels which results in elevation of their noise levels above all other channels. If signal from such suboptimal channels is incorporated during the final coil combination their artificially high noise floor is added to the reconstructed image and may result in degraded image quality. Especially when imaging techniques are used that already suffer from low SNR, noisy channels may completely destroy the features of the reconstructed image. Aim of this work was therefore to develop and implement an automatic k-space based algorithm which first identifies the channels that suffer from strong noise and contain no valuable signal, and then excludes the contributions of these channels from the reconstruction process directly before the final coil combination. The potential of our algorithm to improve the overall image quality and its robustness is demonstrated in 3D high resolution T_2*-weighted gradient echo images acquired in a pediatric patient with osteosarcoma.

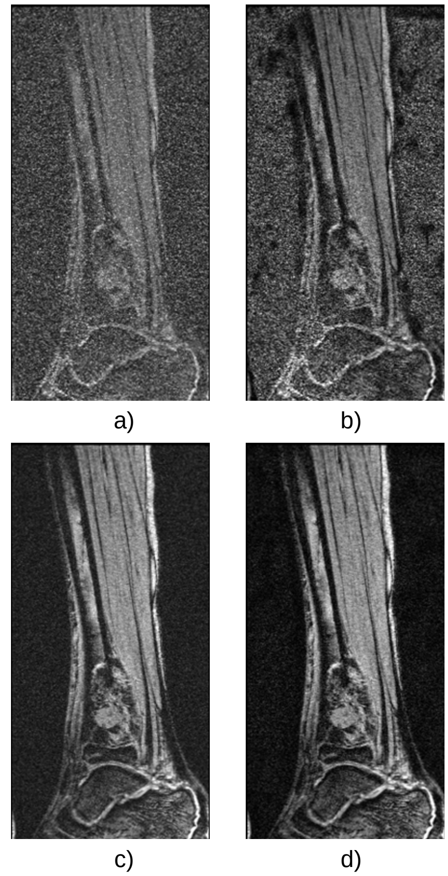

Figure 1: Reconstructed magnitude images of a 10-year-old child with osteosarcoma. The top row shows the original, uncorrected SoS (a) and AC (b) images, containing one NCI-positive channel. The corrected SoS (c) and AC (d) images reconstructed without the NCI-positive channel are shown in the bottom row.

Material and Methods: An automatic coil selection algorithm as described in [3] and [4] is usually performed in the image domain and requires knowledge about the coil sensitivities. If such information is not available or cannot easily be extracted, statistical methods in the image domain may be used to distinguish between channels with and without signal. However, if the signal is compromised and the SNR is low, a statistical image domain approach is prone to errors and may lead to erroneous results. To overcome these limitations, we propose an alternative approach that works solely in the frequency domain. In theory, the magnitude of the complex-valued k-space contains a signal peak at the center of the k-space (the low spatial frequency part) which falls off rapidly, leading to very low signal contributions at peripheral sections of k-space (the high spatial frequency part). Due to the very low signal in the periphery, we expect a low mean and a low standard deviation compared to the high signal at the k-space center. Based on these assumptions, k-space data with a significant high peripheral mean and standard deviation in relation to the signal at the k-space center are considered to be data points of very weak signal and high noise. From these observations, the following coil detection algorithm can be derived: First, the magnitude k-space data of each channel will be scaled between 0 and 1 and the position of the k-space center will be determined. Second, the corners of the k-space will be used to calculate the $mean_j$, the standard deviation std_j and the noise power $n_j = mean_j^2 \cdot std_j^2$ for each channel j. Third, a noisy channel indicator (NCI_j) is obtained for every channel by rating each element of n_j with the modified z-score outlier detection algorithm [5]. Each channel with NCI > 10 is referred to as a NCI-positive channel, whereas each channel with NCI ≤ 10 is referred to as a NCI-negative channel. NCI-positive channels are considered noisy signal channels and will be discarded from the subsequent reconstruction process. The proposed method was implemented as a functor in the Siemens ICE framework and integrated into the standard reconstruction pipeline, right before the phase encoding Fourier transform took place. The already performed read out Fourier transform was reversed to obtain a full k-space. After the identification of the NCI-positive channels, each NCI-positive channel will be discarded by setting the channel information to zero. This algorithm was tested in a clinical case of a 10-year-old child diagnosed with osteosarcoma of the right distal tibia. The image acquisition and reconstruction was performed on a whole body MR-Scanner (1.5T Magnetom Avanto, Siemens Medical Solutions, Malvern, PA, USA) and the presented dataset was acquired with a susceptibility weighted 3D gradient recalled echo sequence [6] using the following parameters: TE = 22.59ms, TR = 60ms, $\alpha = 20°$, slice thickness = 1mm, field of view = 256x128mm^2, matrix = 384x192x47. In this exam, two flexible coil arrays were placed above the legs and the spine coil array was positioned posterior. Coil selection and adjustment were conducted automatically without user interaction. For comparison corrected and uncorrected images were computed by applying the combination techniques Sum of Squares (SoS) [1] and Adaptive Combine (AC) [7].

Results: The magnitude images reconstructed from the same raw dataset with and without correction are presented in Figure 1. The top row shows the original, uncorrected SoS (a) and AC (b) images while the bottom row shows the corrected SoS (c) and AC (d) images. The uncorrected images (a, b) are impaired by strong noise due to one NCI-positive channel. After processing the data according to the proposed method, the NCI-positive channel is identified and discarded, resulting in a significant improvement in image quality and a gain in SNR for both the SoS (c) and AC (d) images.

Discussion & Conclusion: With the proposed procedure we were able to identify suboptimally activated phased array channels, which are impaired by strong noise and therefore contain no or only very weak signal. By discarding these channels from the image reconstruction process the overall image quality and the SNR could be significantly improved, especially in low SNR imaging scenarios. The method was implemented on the MR-Scanner and works on the fly. In order to assure proper function of the modified z-score algorithm the number of channels with sufficient signal must exceed the number of those without. Any influence of our algorithm on advanced imaging techniques such as the GeneRalized Autocalibrating Partially Parallel Acquisition (GRAPPA) [8] has to be further investigated. However, we expect no negative effect on GRAPPA - in fact if only noise containing channels are discarded before the GRAPPA reconstruction, GRAPPA may benefit from our algorithm as well.

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