Advanced Parallel Imaging Techniques for Multi-Shot Axial Continuously Moving Table MRI

S. Kannengiesser[1], H-P. Fautz[2]

[1]Magnetic Resonance Division, Siemens Medical Solutions, Erlangen, Germany, [2]Department of Radiology, Section of Medical Physics, University Hospital Freiburg, Freiburg, Germany

Introduction

Continuously moving table MRI (or Move During Scan, MDS) with axial slices yields good results when performed with single-shot techniques, e.g., [1,2]. These, however, have limited resolution when turbo-spin echo (TSE) sequences are used. When multi-shot TSE-MDS is attempted, acquisitions contributing to a single image are necessarily measured at substantially different positions in the magnet, and with a temporal difference equal to the repetition time TR, which may result in data inconsistencies leading to ghosting artifacts. Here we introduce intrinsically calibrated parallel imaging to significantly improve image quality and information content in these situations.

Cyclically line shifted acquisitions of a time series in dynamic imaging can be accelerated by techniques like UNFOLD [3] and TSENSE [4]; static imaging can be made more robust against motion effects by simultaneously using parallel imaging techniques and multiple averages, as for example in [5]. Below we describe the application of similar concepts to MDS imaging, treating the stack of images as a series in space and time, with a slowly varying image content in both domains.

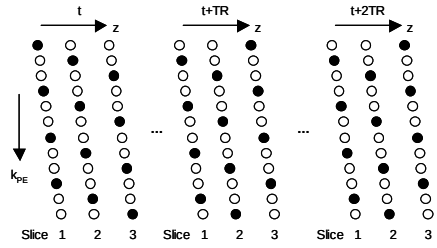

Figure 1: Cyclically line shifted slice interleaved *k*-space MDS acquisition scheme with 3 excitations at successive TRs per slice, and 3 slices. The dots represent acquired ● and not acquired ○ *k*-space lines. The patient table moves in the +*z* direction.

Materials and Methods

Figure 1 shows a generic 2D MDS multi-slice acquisition with intrinsic calibration properties. Both neighboring slices and successive acquisitions can be combined for sensitivity estimation, which requires some additional treatment to suppress ghosting in the sensitivity information, e.g., low-pass filtering. Each individual acquisition can then be reconstructed separately with parallel imaging.

Free-breathing axial 2D multi-slice MDS imaging of healthy volunteers was performed after informed consent with a 3-shot TSE sequence capable of acquiring either multiple acquisitions of the same anatomical slice (type A), or incrementally shifted acquisitions (type B). The echo spacing was 4 – 5 ms, with a half-Fourier echo train length of 30 – 35. The FOV was typically 500 x 260 mm^2 at a base resolution of 384, and with a slice thickness of 5 – 6 mm.

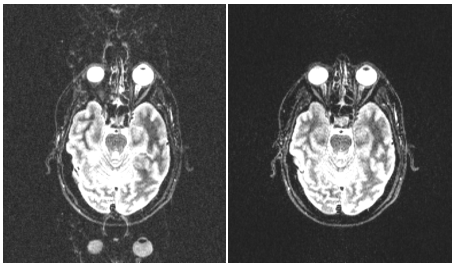

Figure 2: Type A STIR MDS imaging without (left) and with GRAPPA*3, and 3 averages (right).

Parallel imaging reconstruction with acceleration factor 3 in A-P of the individual data sets was performed using essentially the standard scanner software implementation of GRAPPA. Sensitivity information was extracted from acquisitions belonging to the same anatomical slice or its nearest incrementally shifted neighbors. The reconstructed individual images were averaged to suppress residual artifacts caused by patient motion or inconsistencies in the gradient nonlinearities between excitations.

All experiments were performed on a 1.5 T Siemens Avanto scanner with 32 receive channels and the standard setup of local receive coils covering the whole body with 60 matrix coil elements. Such a moving coil setup has already been found to be well-suited for MDS parallel imaging with *k*-space based methods [6]. Subsets of the coil arrangement were dynamically selected depending on the position of the patient table relative to the scanner's isocenter. The speed of the patient table was 7 – 10 mm/s.

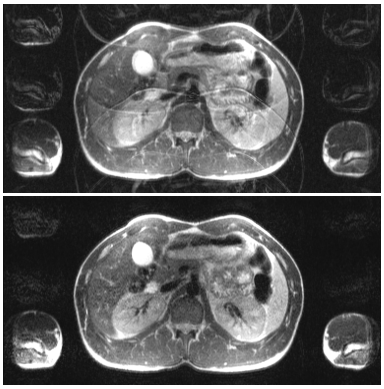

Figure 3: Type A T_2 weighted MDS imaging without (top) and with GRAPPA*3, and 3 averages (bottom).

Results

Figure 2 shows eye motion artifacts in short TI inversion recovery (STIR) type A images of the head, which are completely removed by GRAPPA and averaging. Figure 3 shows a mixture of artifacts in abdominal T_2 type A images caused by breathing and gradient nonlinearity inconsistencies, which are also almost completely suppressed with GRAPPA and averaging. In Figure 4 T_2 images near the shoulder of type B are shown. Again the gradient inconsistency artifacts are efficiently suppressed by GRAPPA and averaging.

Discussion and Conclusion

Averaging as a method for sensitivity estimation and image combination is only a very simple spatial filter. Other types of filter, like band-pass filtering in the *z*-direction, or maximum intensity projection across slices with the same anatomical position, are expected to have improved performance. Especially the type B images should be filtered while preserving some of the improved resolution in the *z*-direction.

Since the data acquisition can be configured to allow for even higher numbers of acquisitions at each anatomical location, a retrospective analysis of the motion pattern seems feasible. Of course, also image series acquired with a stationary patient table can be treated with the same methods introduced here.

In conclusion, intrinsically sensitivity calibrated acquisition strategies in axial MDS imaging combined with advanced parallel imaging reconstruction permit high-quality, high-resolution multi-shot TSE imaging which is robust against artifacts caused by motion and gradient nonlinearities. This is an important prerequisite for the clinical use of axial TSE-MDS, for example in metastasis screening [7].

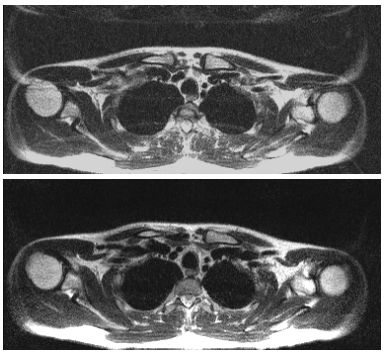

Figure 4: Type B T_2 MDS imaging without (top) and with GRAPPA*3, and 3 nearest neighbor averages (bottom).

References

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