Technology Offer

Technique for calibrating and processing magnetic resonance imaging data

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Abstract

Two groundbreaking technologies are introduced, offering substantial enhancements to the precision and efficiency of Magnetic Resonance Imaging (MRI) by auto-calibrating spin phase information directly from imaging data.

The first invention presents a method to extract spin phase evolution maps – arising from arbitrary spatial encoding fields that continuously oscillate and evolve during signal acquisition – using existing imaging data without the need for additional field mapping scans. This data-driven approach significantly enhances calibration precision, enabling the use of fast-oscillating linear and nonlinear encoding fields that were previously limited by inaccurate calibration and artifact introduction. As a result, it allows for faster and more robust MRI – all without separate calibration scans.

The second invention introduces another auto-calibration method that enables the extraction of shot-to-shot spin phase fluctuations from overlapping imaging data at arbitrary k-space locations – a capability previously considered unattainable. This advancement facilitates a wide range of multi-shot MRI techniques without the need for navigator scans.

Together, these two technologies calibrate spin phase dynamics occurring both during acquisition and between acquisition shots. They significantly enhance image quality, reduce scan time, and thus serve as invaluable foundations for fast and high-resolution MRI with exceptional robustness across a wide range of clinical and research applications.

Background

MRI is a widely-used imaging technique in medical diagnostics and neuroscience, renowned for its ability to non-invasively provide detailed structural and functional images of soft tissues without the use of ionizing radiation. To achieve fast and high-resolution imaging, methods such as parallel imaging, nonlinear gradient encoding, and multi-shot Echo-Planar-Imaging (EPI) have been developed to spatially encode MR images using distinct spatial encoding fields and multiple acquisition shots.

However, these advanced techniques require highly precise calibration of magnetic fields or spin phase fluctuations to ensure artifact-free image reconstruction. Our two innovative auto-calibration methods address this critical need by efficiently calibrating spin phase dynamics directly from imaging data, during signal acquisition and between separate acquisition shots. They serve as foundations for fast and high-resolution MRI, making these scans highly robust and widely-applicable.

Technology

Technique for calibrating magnetic resonance imaging data

The first technology robustly extracts spin phase evolution maps associated with phase modulations induced by fast-oscillating magnetic fields, including both linear and nonlinear gradients. By precisely quantifying the effects of these intricate oscillations, this method serves as a critical calibration step that enables fast imaging without introducing artifacts. Unlike prior art methods that reply on separate calibration scans, this solution utilizes the imaging data itself to estimate continuously evolving phase maps, substantially enhancing estimation accuracy and eliminating redundant calibration procedures.

By capturing the combined effects of spatial encoding fields, eddy currents, field nonlinearity and system imperfections, this data-driven approach is highly error-resilient and widely-applicable, especially in scans where advanced oscillating fields are employed to achieve rapid imaging. The effectiveness of the presented auto-calibration technique is demonstrated in Figure 1, which compares reconstructed in-vivo brain scans accelerated by additional oscillating spatial encoding fields, both without and with the application of the invented method.

Max-Planck-Innovation GmbH
Arnulfstr. 58
80335 München
www.max-planck-innovation.de

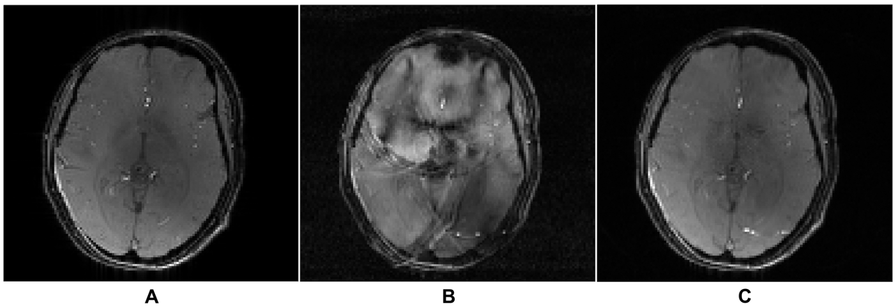

Figure 1.(A) Reference image without acceleration by additional oscillating spatial encoding fields. B.) Image reconstructed from 3x3 accelerated scans with additional oscillating spatial encoding fields. The conventional calibration method based on explicit field-mapping scans and current monitoring is used to estimate the additional spin phase evolution imposed by the fast-oscillating spatial encoding fields. Strong artifacts appear in reconstruction due to the calibration errors in the estimated phase evolution maps. (C) Image reconstructed from 3x3 accelerated scans with additional oscillating spatial encoding fields. The spin phase evolution maps used for reconstruction is obtained by the auto-calibration method as described in this tech offer, which enables artifact-free highly accelerated MRI.

Technique for processing magnetic resonance imaging data

The second technology introduces an efficient method to phase stabilize multi-shot MRI data, enabling robust high-resolution imaging that is invulnerable to shot-to-shot phase variations. This is particularly useful for diffusion and functional imaging applications. This technique focuses on extracting phase fluctuation maps that vary across separate acquisition shots, by utilizing overlapping regions at arbitrary k-space locations. By applying the proposed subspace algorithms, the shot-dependent phase fluctuations can be robustly extracted from the overlapped imaging data without need for additional navigator scans.

This reduces scan time by a few tens of millisecond per shot, and avoid possible inconsistency between navigator and imaging echoes or shot-dependent system imperfections. As a special case, the invented algorithms can also serve as a subspace “filter” to robustly extract phase fluctuation maps from the navigator data, outperforming their conventional explicit extrapolations. Figure 2 demonstrates a 5-shot diffusion-weighted readout-segment EPI image (i.e. 0.7 mm^2, no 2D navigator, b=1500 s/mm^2, sum of 20 diffusion directions) without corrections for shot-to-shot phase variations (A), and with corrections based on our invented technique to stabilize inter-shot image phase (B).

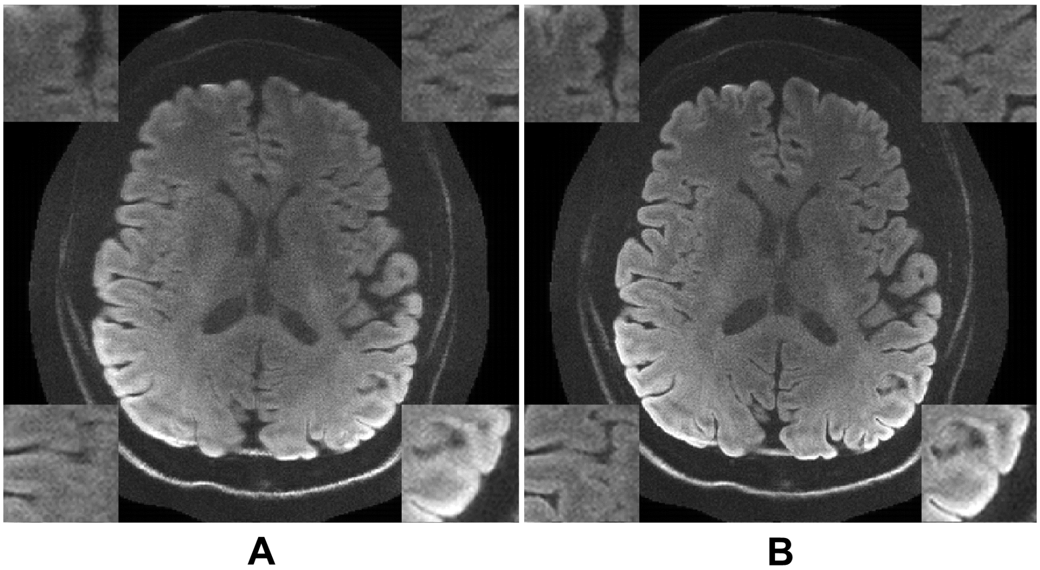

Figure 2: Comparison of an uncorrected (A) and a corrected 5-shot diffusion-weighted readout segmented EPI image using the technology presented in this tech offer (B).

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Arnulfstr. 58
80335 München
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Advantages

Technique for calibrating magnetic resonance imaging data

- Enhanced quality of fast MRI accelerated by a wide-range of fast-oscillating spatial encoding fields.
- Data-driven auto-calibration of spatial encoding fields without additional field mapping scans.
- Robust against noise, field imperfections, eddy currents and motions.
- High calibration accuracy for both linear and nonlinear spatial encoding fields.
- Reduction in calibration scan time by eliminating field mapping scans.

Technique for processing magnetic resonance imaging data

- Effective enhancement of image resolution and reduction of geometric distortion.
- Robust extraction of spin signal fluctuations across multiple shots.
- Enabling a wide-range of navigator-free MRI sequences.
- Reduced scan time, e.g. 30-50 ms per shot of acquisition, compared to a 2D navigator-based multi-shot MRI technique.
- Effective filter to remove noise and errors in navigator echoes, as a special case for conventional navigator-based EPI.

Potential applications

Technique for calibrating magnetic resonance imaging data

- MRI systems using linear and nonlinear spatial encoding fields.
- Calibration of MRI gradient hardware.
- High-resolution and fast MRI scans.
- Advanced clinical MRI, e.g. for neurology and cardiology.
- MRI research in developing field calibration techniques.

Technique for processing magnetic resonance imaging data

- High-resolution multi-shot MRI.
- Functional MRI.
- Diffusion-weighted MRI for structural characterization.
- Advanced imaging for neuroscience.
- Advanced diagnostic imaging.

Patent Information

PCT application (2024/060514 and 2024/060513).

Contact

Dr. Bernd Ctortecka

Senior Patent- & License Manager, Physicist
Phone: +49 (0)89 / 29 09 19 – 20
eMail: ctortecka@max-planck-innovation.de

Max-Planck-Innovation GmbH
Arnulfstr. 58
80335 München
www.max-planck-innovation.de