Adaptive magnetic field mapping to accelerate the B_0 shimming process in a low-field MRI using Gaussian process regression

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Introduction: The homogeneity of the static magnetic field B_0 is a decisive factor for image quality in magnetic resonance imaging (MRI) [1]. This is especially true in low-field MRI systems, such as those based on permanent magnet arrays around 50 mT, where field inhomogeneities are pronounced and difficult to correct. A key challenge in these systems is the efficient acquisition of the B_0 field map required for the shimming process [2,3]. Conventional techniques typically rely on dense 3D grid measurements, which are time-intensive and often impractical, particularly for iterative or interactive shimming procedures [4]. To address this, we present a real-time adaptive magnetic field mapping approach that selectively samples regions of high inhomogeneity or model uncertainty. This significantly reduces measurement time without compromising accuracy.

Methods: A cost-effective modular measuring system based on a converted 3D gantry has been developed. Despite its rudimentary mechanics, it allows precise sub-millimeter 3D scans using IMU sensor-based calibration procedures to correct mechanical tolerances. A bounding-box model ensured collision-free operation in constrained geometries. The adaptive measurement algorithm initializes with a coarse-resolution survey scan, based on which a probabilistic modeling of the magnetic field is performed using Gaussian Process Regression (GRP) [5]. It is based on its ability to provide a continuous field distribution and a spatially resolved, quantitative uncertainty estimate. Based on the posterior variance, new measurement points are added in regions of maximum model uncertainty in each iteration. The measurement process is continued in closed loop operation, until the uncertainty predicted by the model in the volume is below a predefined value [6].

Results: In addition to the simulation data, the OSII 30 cm Halbach magnet was measured to evaluate the adaptive measurement strategy [3]. A reference scan with 10 mm point spacing over a Volume of 200 mm length and 200 mm diameter yielded 7k points and required a total scan time of 36 hours. The adaptive GPR-based method required only about 1k points of specially selected measurement points (Fig. 1), resulting in an 85 % reduction in time. This resulted in an MSE of 15.4 uT and an MAE of less than 92.6 uT, leading to an overall inhomogeneity loss of 348 ppm compared to the reference. This is acceptable as the overall homogeneity of the field in the reference is 36k ppm.

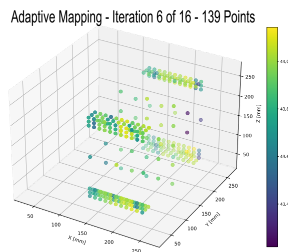

Fig. 1: Initial survey measurement in the center with 100 points. After the 6th of 16 iterations, 395 were added, mostly placed on the shell of the magnet volume.

Conclusion: The presented method for real-time adaptive magnetic field mapping using GPR demonstrates a reduction in the measurement effort for interactive user B_0 shimming applications in low-field MRI systems. The number of required measurement points can be significantly reduced in intermediate shimming steps, thus significantly reducing the iteration time.

References:
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