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Normalized Quantitative Assessment of Receive-Coil Sensitivity using MPI Transfer Function Measurements

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Abstract

In human-scale magnetic particle imaging (MPI), field inhomogeneities arise because a large fraction of the bore volume is utilized for imaging. Accurate knowledge of the receive-coil sensitivity is essential for hybrid system-matrix generation and model-based system matrix reconstruction. In this work, we present an efficient approach for measuring normalized receive-field profiles using a calibration coil and a small number of measurements.

I. Introduction

Human-scale MPI systems utilize a substantial fraction of the bore volume, where power constraints limit increasing field homogeneities via larger coils [1]. Since the dimensions of the field of view (FOV) are comparable to the diameter of the coils, inhomogeneities in the magnetic fields are unavoidable which affect both the drive field and the receive-coil sensitivity. These variations can hinder gradiometric receive-coil designs, motivating the development of alternative topologies such as gradient or customized matrix coils [2]. Consequently, a single center-point sensitivity measurement is insufficient, particularly for gradient coils where the central sensitivity is near zero. Extending MPI receive path calibration to spatially resolved measurements using intelligent sampling [3, 4] enables systematic assessment of the full receive-coil field profile, supporting iterative coil optimization, hybrid system-matrix generation, and model-based reconstruction [5, 6].

II. Methods

For the seven receive channels of the head-sized MPI system (Fraunhofer IMTE, Lübeck), the transfer function, proportional to the MPI transfer function $\hat{G}$ and representing transmission from a three-dimensional calibration coil to the system's analog input, was measured [2, 3]. To preserve the validity of magneto-quasistatic approximations, spatial displacement of the calibration coil should only affect the amplitude and sign of the transfer function while maintaining its phase. When this condition is met, a single frequency component with sufficient signal-to-noise ratio is adequate to characterize the full field profile. To drive the calibration coil with sufficient power, a sinusoidal signal at 97.656 kHz was generated

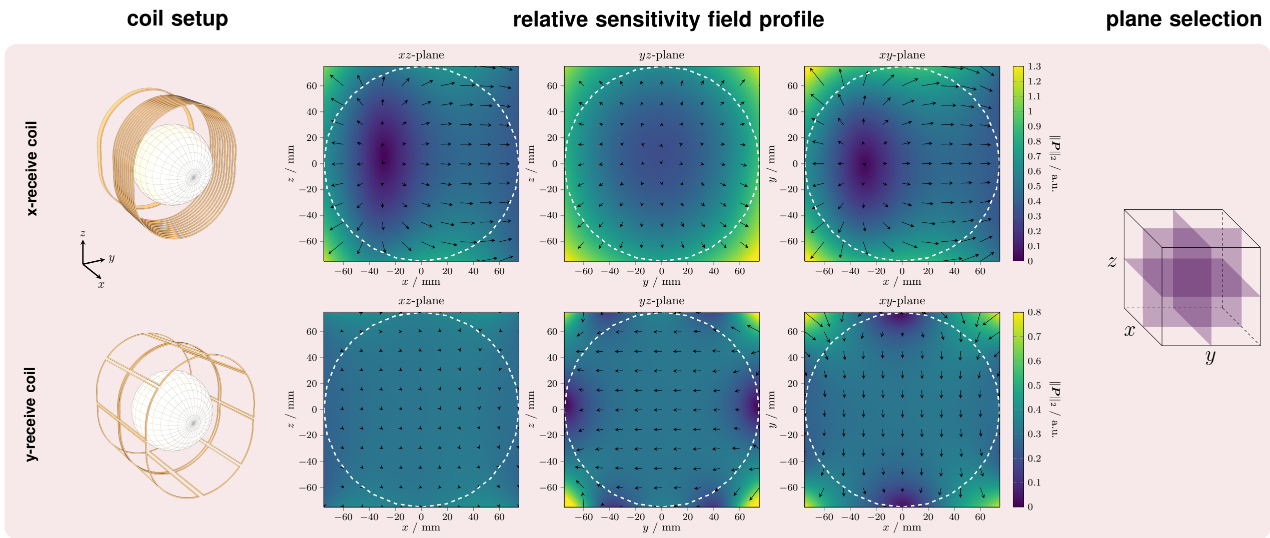

Figure 1: Spatial receive sensitivity field profiles of the gradiometric and the matrix receive coil. Left: Coil rendering including the 150 mm sphere. Middle: Receive sensitivity field profiles for the three central planes. The magnitude of the normalized sensitivity |P| is represented by color coding, while the arrows indicate the local field direction. Within the spherical boundary (white circle), the field expansion is valid; values outside this region should be disregarded. Right: Illustration of the corresponding planes.

and amplified using a Crown XLI 800 PA amplifier (HARMAN International, Stamford, USA). Receive voltage signals $\hat{U}_{\text{in}}$ from all seven channels were simultaneously digitized along with the coil current $\hat{I}_{\text{cal}}$ using the system DAQ and a current probe. From this, the relative receive coil sensitivity P becomes

$$P(\mathbf{r}) \propto \hat{G}(\mathbf{r},k) = \hat{G}(\mathbf{r}_s,k)P(\mathbf{r}_s)^{-1}P(\mathbf{r}) \propto \frac{\hat{U}_{\text{in}}(\mathbf{r},k)}{\hat{I}_{\text{cal}}(\mathbf{r},k)}, \qquad (1)$$

where $\mathbf{r}_s$ is any position $\mathbf{r}$ outside sensitivity nulls. The calibration coil, with seven turns per axis and a 5 mm radius, was sequentially placed at 86 positions on the surface of the sphere (150 mm diameter) to enable spatial receive field profile characterization via solid harmonic expansions.

III. Results and Discussion

In Figure 1, the normalized relative receive-coil sensitivity profiles are represented as,

$$|P| = \text{sgn}\big(\cos\big(\arg(\hat{P}_i)\big)\big) \cdot |\hat{P}_i|, \quad \text{for } i \in \{x,y,z\},$$

for two receive coils, a gradiometric and a matrix coil, implemented in a human-scale MPI system. The spatial field orientation and inhomogeneities can be directly evaluated. This approach enables normalized quantitative measurement and analysis of the receive-coil sensitivity profiles, facilitating iterative coil optimization. It inherently accounts for distortions due to coil manufacturing tolerances, eddy current effects, and the influence of feeding wires, often neglected in simulations. Accurate field data obtained in this manner improve MPI scanner models, supporting hybrid system-matrix generation and model-based system matrix reconstruction.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

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