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Spatial encoding with receive coils in MPI

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Abstract

MPI techniques traditionally use gradient magnetic fields for spatial encoding. Despite their proven efficiency, these methods are power-intensive and technically challenging to implement on a human scale. In this work, we explore the potential for spatial encoding of superparamagnetic nanoparticle distributions using only a drive field and an array of receiving coils with unique spatial sensitivity profiles. We demonstrate the feasibility of this concept using a prototype 1D imaging system extended to 2D by mechanically moving the sample. The proposed approach permits high-speed gradient-free data acquisition for rapid imaging but also has some limitations in terms of penetration depth.

I. Introduction

Over the years, several spatial encoding techniques for MPI have been proposed, including field free point [1], field free line [2], and traveling wave [3] approaches. Despite their differences, they all fundamentally rely on magnetic field gradients to spatially localize superparamagnetic nanoparticles. Although field gradients have proven viable for this task, their generation can be technically challenging and power-inefficient, especially when aiming for acceptable resolution in human-sized applications [4]. At the same time, it has been shown that MPI can be performed without magnetic field gradients [5], which opens the way for new spatial encoding concepts. One such option is the implementation of arrays of receive coils, similar to those used in MRI [6]. However, two major limitations exist for a straightforward transition to the same technology. First, the phase shift at MPI frequencies is too small to be detected with sufficient accuracy when measured between signals from parallel receive coils. Second, the receiving coils need to be gradiometric to eliminate the presence of the drive field. Both problems can be solved by utilizing coils with orthogonal sensitivity profiles and limiting the detected phase changes to two values: 0 and 180 degrees.

II. Methods and materials

To demonstrate the concept of spatial encoding with the receive array we build a prototype for a 1D MPI system. It is based on work in [7], where the same approach was used for a field synthesis task. We employed similar geometry and dimensions, but instead of five coils, we made ten, since our task requires reconstructing the position of arbitrarily placed field sources. To reduce losses in the conductors, we used Litz wire, which was placed inside the 3D-printed platforms. The drive field coil was located on the top of the receive coil array and represented by two eight-winded flat spiral coils for the generation of a vertically oriented 6 mT 25 kHz field. It also was positioned so that all the receiving coils were gradiometric relative to it, effectively rejecting the fundamental frequency. As the source of the signal and as

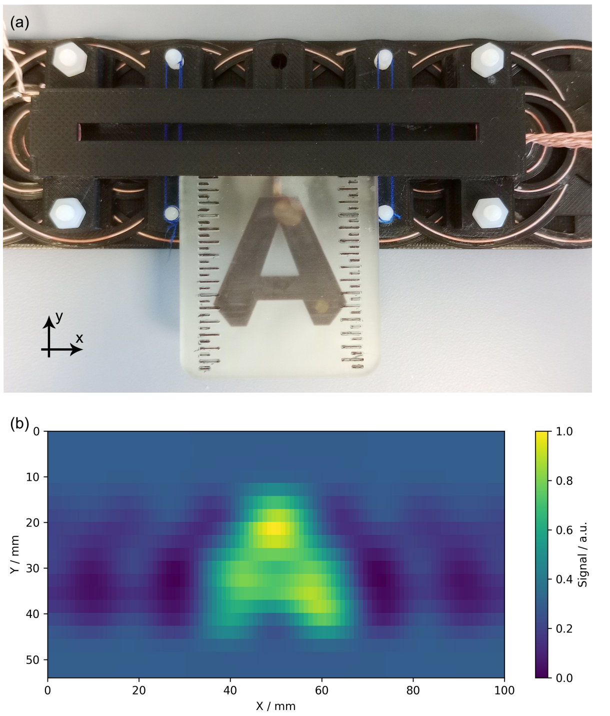

Figure 1: a) The prototype of 10 channel 1D MPI system and b) a reconstructed image of the sample. The position of the encoding line roughly coincides with the visible slot in the drive field coil.

a receiver, we used the RedPitaya IO board. The single-channel receive chain was equipped with a 25 kHz band-stop receive filter and during the experiments connected sequentially to all ten channels for each position of the sample. Only the third harmonic was measured. As the imaging sample, we used a 45x50 mm vessel filled with undiluted Resotran ® (28 mg/ml).

III. Results and discussion

The sensitivity profiles of the coils are similar to sine and cosine functions with different spatial frequencies, which enables the measured signal values to be used as coefficients for the Fourier series. The reconstruction task concludes with a simple summing algorithm [7], requiring only ten values as input for each scanning line. The reconstruction result is shown in Figure 1.

Since only five spatial frequencies are used, Gibbs artifacts are visible in the image. The resolution in the encoding direction (x-axis) is strictly determined by the smallest coil diameter in the array, which in our setup is about 10 mm. The penetration depth of such a system is also related to the size of the smallest element of the array, since the sensitivity of the coils decreases rapidly with distance, as does the overall resolution.

IV. Conclusions

In this work, we demonstrate the concept of a receive coil array for MPI based on coils with orthogonal receive sensitivity profiles. This approach permits us to reconstruct the spatial distribution of superparamagnetic nanoparticles without using magnetic field gradients and requires only a drive field to excite the particles. However, it also has significant potential for integration with existing gradient-based methods to improve their performance.

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Author’s statement

Conflict of interest: Authors state no conflict of interest.

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