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Algorithm for computing optimal SNR thresholds of a single-sided FFP MPI device

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Abstract

Due to the topology of a single-sided MPI device, the magnetic field suffers from inhomogeneities which are limiting the penetration depth. Additionally, the sensitivity profile of the receive coils compromises the measured signal. Therefore, the signal spectrum shows a relatively high noise level. To achieve a sufficient reconstruction and reduce the reconstruction time, only the frequency components are used, that have a sufficiently high signal to noise ratio (SNR). The algorithm presented in this paper allows for computing optimal SNR-thresholds which promise reconstructed images with high quality. For now, the algorithm is limited to 2D-reconstruction, but it already promises to enhance the existing reconstruction algorithm for the single-sided field free point MPI device significantly.

I. Introduction

Magnetic Particle Imaging (MPI) is a medical imaging modality which was presented in 2005 by Weizenecker and Gleich [1]. To overcome the challenge of a limited object size, the first field free point (FFP) single-sided MPI device was developed by Sattel et al. [2]. Since then, the principle of single-sided MPI has been enhanced, what leads to the first 2D images of such a single-sided device [3] and the first 3D images [4,5]. In addition to systems using an FFP, there is a single-sided MPI device that uses a field free line (FFL). This FFL system promises a higher penetration depth of up to 30 mm and a higher response signal by a factor of 10 [6].

In this work, we present an algorithm for computing the optimal SNR-thresholds for an FFP single-sided MPI device.

II. Material and methods

II.I. Single-Sided MPI Scanner

The single-sided MPI device, which this paper is based on, has been presented in [3,4,5]. It features two D-shaped and two circular coils positioned on the same side of the field of view (FOV). Those are complemented by three receive coils. The magnetic field of the scanner is shown in Fig. 1, in which the decrease of the field strength and the increase of the size of the FFP with larger distance to the scanner surface can be observed.

The reconstruction of the measured data is done in the frequency space using a measured system function. Therefore, the data is transformed by a discrete Fourier transformation. For sufficient reconstruction time and quality only those frequency components are used, that have an SNR higher than a certain threshold. To calculate an SNR a position close to the scanner surface and centered at the vertical axis is used. Fig. 2 shows the SNR for the x channel of the scanner. The SNR plot in

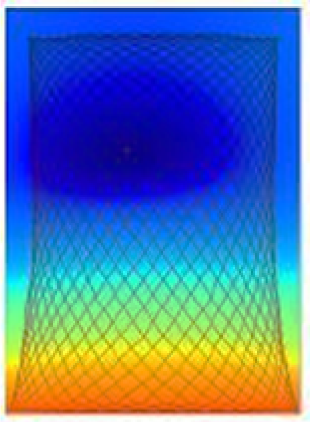

Figure 1: Simulated magnetic field strength of the single-sided MPI device including a Lissajous trajectory on which the FFP is moved over the FOV. The deep blue oval shaped spot is the FFP.

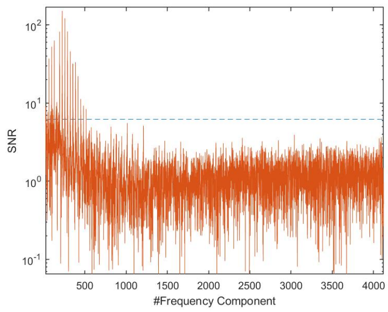

Figure 2: SNR plot for the x-channel of the used system function. The blue dotted line is the calculated SNR-threshold for the x channel.

Fig. 2 shows a high noise level, which makes it difficult to determine an adequate SNR threshold. In the past those thresholds were selected manually using a SNR-plot similar to Fig. 2 or by visual assessment of image quality [3, 4].

II.II. Phantom and Measurements

To calculate the system function a cubic sample with a side length of 2 mm is used, which is filled with 8 µl Resovist (Bayer Schering Pharma, Berlin, Germany). This sample is positioned by a microstep robot (isel Microstep Controller c124-4, iselautomation, eitfeld, Germany) at 256 positions in the 32 mm x 32 mm FOV while the measurement is done. Additionally, a second system function is measured from which the particle measurements are taken that are used for the reconstructed images. Both the system function and the measurement data are corrected by subtracting an empty system function and an empty measurement, respectively.

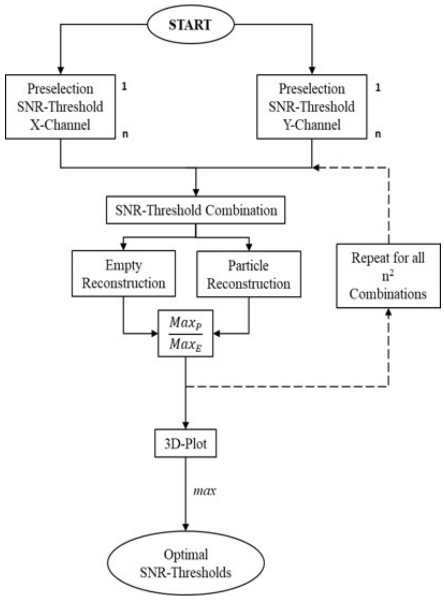

Figure 3: Flowchart of the algorithm for computing the optimal SNR-thresholds of a 2D system function for a single-sided MPI device.

II.III. Algorithm

Fig. 3 showcases the function of the algorithm to compute appropriate SNR-thresholds in a flow chart. The algorithm uses a particle measurement positioned at the point where the SNR is calculated, about 1 mm above the scanner surface and centered on the vertical axis. Also, an empty measurement is needed. First, possible SNR-thresholds for both the x- and the y-channel must be preselected. The number of those determines the number of reconstructions needed for the algorithm. With a preselection of high quality less reconstructions will be needed. In the following, one SNR-threshold is chosen for each direction and a reconstruction process for the particle measurement close to the scanner surface and for the mentioned empty measurement is performed. Then from both of the reconstructed matrices the respective highest value, i.e. maxP for the particle measurement and maxE for the empty measurement, is taken to determine the ratio maxP/maxE. This is done for all combinations of possible SNR-thresholds.

By maximising this ratio, the least influence of the noise on the signal is determined, as a reconstructed empty measurement represents the noise level of the system.

The calculated ratio is plotted versus the SNR-thresholds for the x- and y-channel, and the highest ratio determines the final SNR-threshold for both directions.

The optimal SNR-thresholds are a property of the system function and need to be calculated only once for a certain system function using the presented algorithm. This was proven by changing the position of the particle

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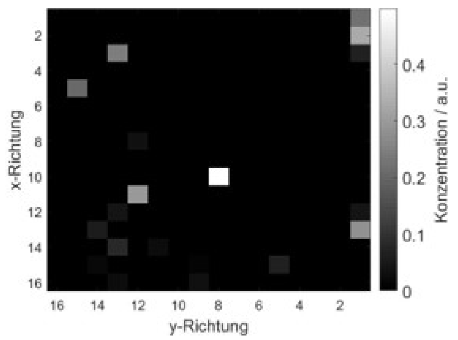

Figure 4: Reconstructed image of a 32 mm x 32 mm FOV with a particle sample of 8 µl Resovist in a distance of 14 mm to the scanner surface and positioned on the vertical axis. The reconstruction was done with SNR-thresholds of 6.2 for the x-channel and 5.8 for the y channel.

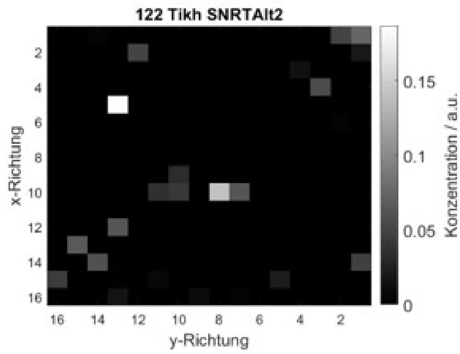

Figure 5: Reconstructed image of a 32 mm x 32 mm FOV with a particle sample of 8 µl Resovist in a distance of 14 mm to the scanner surface and positioned on the vertical axis. The reconstruction was done with the old SNR-thresholds of 4 for both the x-channel and the y-channel.

measurement used in the algorithm and comparing the received thresholds as well as the quality of the reconstructed images.

III. Results and discussion

Fig. 4 shows a reconstructed image for a particle measurement in a distance of 14 mm to the scanner surface, which was positioned on the vertical scanner axis. The image was reconstructed using the thresholds calculated by the algorithm introduced above. Although the image shows some noise, the maximum value of the image, which is at the position of the particle sample is at least 1.5 times higher than all other values in the image. Based on this image the position of the sample can be clearly identified.

The noise level present in the reconstructed image is low in comparison to images of the single-sided MPI scanner with manually chosen SNR-thresholds, especially for the distance of 14 mm, which is about the maximum penetration depth [4]. In Fig. 5 such a reconstructed image can be seen. It features the same particle measurement as in Fig. 4, but it was reconstructed with the manually chosen SNR-thresholds, which were used in the past [3]. However, it has to be stated that the quality of the reconstructed image using the SNR-thresholds from the algorithm depends on the quality of the used system function. If a system function of lesser quality is used the SNR-thresholds computed by the algorithm cannot guarantee a reconstructed image of such high quality.

IV. Conclusions

In order to improve image quality for real MPI systems using system matrix-based image reconstruction, only frequency components whose signal-to-noise ratio exceeds a certain threshold may be used. In the past, these SNR thresholds were often selected manually using a visual image quality assessment. In this work, an algorithm for automatic objective determination of appropriate SNR thresholds was presented. The success of the method was demonstrated for noisy measurement data from a single-sided MPI device.

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Author's statement

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