Sinusoidal PatLoc imaging using matrix gradient coils

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INTRODUCTION: The concept of PatLoc (parallel imaging technique using localized gradients) provides a method for parallel imaging by using nonlinear Spatial Encoding Magnetic fields (SEMs). Alternating SEMs lead to field ambiguities but can be resolved using more RF-receive coils than field ambiguities. All PatLoc implementations so far use nonlinear SEMs based on spherical harmonics and result in a resolution void in the center of the image. A matrix shim coil approach has been shown to be advantageous to create arbitrary fields for shimming and has been used for imaging using linear SEMs [1]. In this abstract we propose the concept of a Rapid Adaptive Nonlinear Gradient Encoding (RANGE) system which is able to create any type of encoding field within physical limits. We demonstrate PatLoc imaging using SEMs based on sinusoidal basis functions to overcome limits of current implementations of PatLoc imaging. This abstract aims for MR- scientists and engineers working in the field of parallel imaging and/ or shim and gradient design.

METHODS: A RANGE-concept matrix coil consists of many independent current carrying elements to create arbitrary magnetic fields for spatial encoding. A whole body system with a length of 100 cm along z (direction of main magnetic field B_0) and an inner diameter of 54cm, consisting of 41 elements equally distributed along the z-direction by 8 angular elements was simulated (fig.1). Each coil matrix element was considered to be represented by a circular arc segment with an independent current flow. In this concept study the engineering details of a possible future realization of such a coil are left out. Magnetic field of each element was calculated using the law of Biot-Savart. Power optimization was done with a Thikhonov regularization resulting in physically reasonable currents for each coil element. The FOV of a coronal slice was chosen 40x40cm. A receive array with 9 receive coils was used to simulate data acquisition on a grid of 101x101 pixel. 5% noise was added in the signal simulation. Image reconstruction was performed with a CG-algorithm [2] with a resolution of 201x201. Sine and cosine are a set of orthogonal basis functions. Encoding fields were constructed by altering the fields in the two encoding directions based on those functions. Two such fields are perfectly orthogonal, but have areas with zero gradient which would lead to a local resolution loss similar to that in the image center in multipolar PatLoc imaging. If the same two fields are shifted by pi/2 the non-zero areas are now where imaging can be performed with the other two fields. To demonstrate encoding with sinusoidal SEMs a total of four SEMs were pairwise concatenated using a simple Cartesian trajectory. One SEM pair generated by matrix coil are shown in Fig.2.

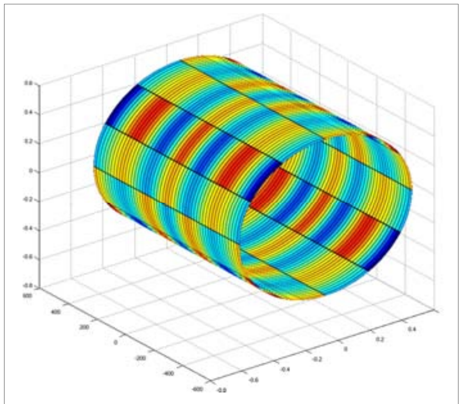

Fig.1: RANGE-system to generate SEMs

RESULTS: A system to create arbitrary SEMs with realizable currents was simulated. This RANGE-system was used to create pairwise perfectly orthogonal SEMs based on sinusoidal functions. Parallel image acquisition and reconstruction was simulated. Fig.3 shows the original and reconstructed image. The local k-space [3] that represents the ability to cover k-space inside the imaged area is shown in Fig.4.

DISCUSSION: The demonstrated RANGE-system gives freedom to scale and match SEMs to the number of available receive coils and the FOV to be imaged. The degree of image parallelization is defined by the chosen number of field oscillations. Additionally the known conventional methods for parallel imaging can be combined with the shown PatLoc method [4] for extremely high acceleration factors. Sinusoidal functions are just one example of an orthogonal basis. Other orthogonal sets like Hermite, Legendre, Zernike, Chebyshev polynomials etc. might be used as basis functions for SEMs. With the RANGE-system imaging of a 3D-volume can further be parallelized in the third spatial dimension. Implementing such a matrix coil in a whole-body system would allow for novel high order shim techniques on the one hand and makes an additional shim system redundant. Novel imaging techniques based on nonlinear SEMs such as curved slice acquisition [5] and spin spoiling [3] can be achieved using a RANGE-system. It remains to be seen how much of the flexibility of the RANGE-concept can be translated into a practical realization of such a coil.

CONCLUSION: Using a RANGE-system for PatLoc imaging with sinusoidal SEMs allows parallel imaging with acceleration factors that exceed the current state of the art methods. The RANGE-system gives freedom for totally new encoding schemes and strategies.

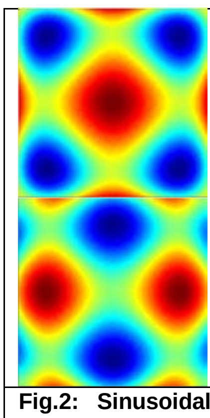

Fig.2: Sinusoidal SEMs for spatial encoding

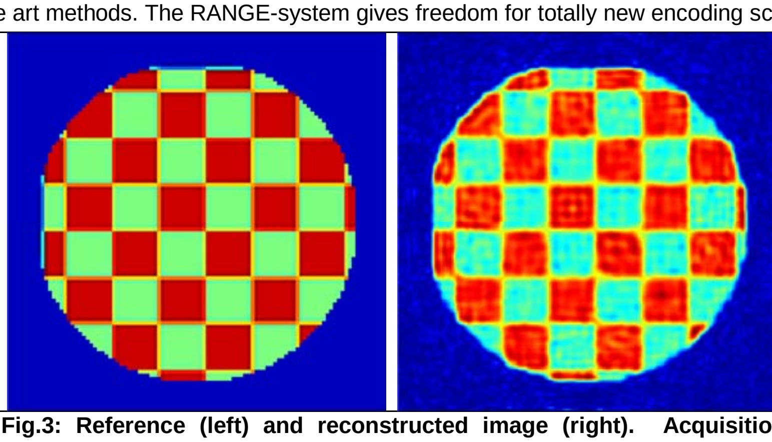

Fig.3: Reference (left) and reconstructed image (right). Acquisition simulated on a grid of 101x101, 5% noise added. Reconstruction was simulated using a CG-reconstruction with a resolution of 201x201.

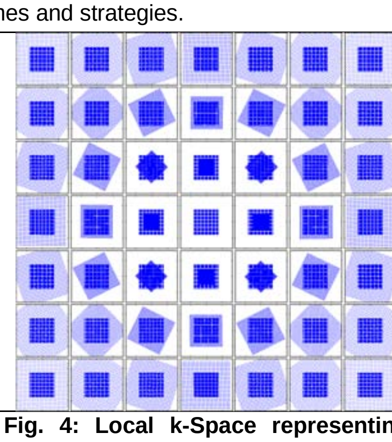

Fig. 4: Local k-Space representing the ability to locally encode using a cart. trajectory and sinusoidal SEMs

REFERENCES: [1] Juchem; JMR 204-2010 [2] Knoll; MRM early view 2012 [3] Witschey; MRM 67-2012
[4] Hennig; MAGMA 21-2008 [5] Weber; MRM early view 2012

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