

Optimized 3D single shot trajectories by Radial arrangement of Individual Petals (RIP)

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With the use of multiple localized, small receive coil arrays, single shot whole brain coverage becomes feasible for fMRI applications using undersampled reconstruction (1,2). Using a 3D rosette trajectory and iterative, regularized reconstruction a 64^3 volume can be acquired in 23 ms with acceptable broadening of the point spread function (3). The analytical rosette trajectory used therein offers only limited degrees of freedom (3 rotation frequencies) to optimize homogenous k-space coverage and point spread function (PSF). In this work we present a method to design and to optimize a 3D single shot trajectory based on an isotropic **R**adial arrangement of **I**ndividual **P**etals (RIP). Optimization criterion is the width and global smearing of the PSF.

Materials and methods: All experiments were performed on a 3T scanner (Trio, Siemens) using a 32 channel head coil array for signal reception. For each session a fully encoded reference volume was acquired with a 3D double gradient echo sequence (TR/TE₁/TE₂=20/5/9.35 ms, fov=256mm, res=64³). Coil sensitivities, an anatomical image and a static field map estimation were derived from this dataset. Single voxel excitation was performed using a PRESS excitation module with a voxel size of 3mm³ (nominal resolution 4mm) in the middle of a water bottle phantom and *in vivo*. Visual stimulation was performed by presenting a flickering checkerboard with alternating rest and stimulation periods (3x) each 10s long.

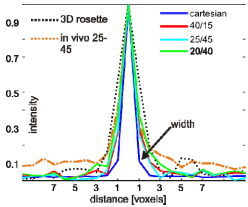


Fig.3) measured PSFs (N/α) using single voxel excitation on water phantom and *in vivo*

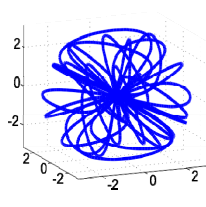


Fig.2) Measured loops trajectory, N=25, α=45°

Trajectories: A single ‘petal’ (2D-loop) is defined by $k_x(t)=k_{max} \cdot \sin(w_1 \cdot t)$; $k_y=a \cdot k_{max} \cdot \sin(w_2 \cdot t)$; $k_z=0$; with $w_2=2 \cdot w_1$, opening angle $\alpha=\tan(a)$ and $t=[0 \text{ } \pi]$. N target points representing the vortices of each petal are then distributed on a sphere with radius k_{max} by minimizing the coulomb energy of N electric point charges. For each target point a planar loop is rotated in order to point in the direction of the target point and smoothly connected to its previous element. The target points are sorted in way that the distance between successive points is maximized in order to minimize the curvature of the connecting gradient shape. Connection of single elements is performed by solving a linear optimization problem with respect to the discrete vector of the gradient shape $g=g_{i,n}$ (4). A RIP-trajectory is therefore characterized by the number of petals N and the opening angle α.

Trajectory measurement and image reconstruction:

The trajectory $K=[k_x, k_y, k_z]$ is determined using a thin slice approach. Each trajectory component k_x, k_y, k_z is measured separately by exciting a thin slice with distance d to the isocentre and orthogonal to the respective gradient axes while switching off the remaining two axes. Offline image reconstruction was performed using MatLab (MatLab Inc.). It is based on solving the inverse problem given by $Ax = b$ where x is the unknown image, b is the measured data and A describes the forward operation of the measurement including coil sensitivity weights and the measured trajectory. The forward operation is evaluated with a non-uniform FFT (nuFFT) algorithm.

The solution is found by minimizing the function $f(x)=||Ax-b||^2 + \lambda||x||^2$ with respect to x , where λ is the regularization parameter. Offresonance correction is performed by deformed interpolation kernels within the nuFFT algorithm (5)

Results: Fig.1 shows the duration (a), the width of the normalized PSF (b) and the

total area under the PSF (c) simulated for various parameters of the loops trajectory. The iso-lines for durations of 20ms and 30ms are drawn as dashed lines. Fig.2 displays the measured trajectory for 25 loops with α=45°. For experimental verification of the simulation results, the PSF was measured (Fig.3). The width and the area under the PSF are displayed in the table. In Fig.4 transversal slices from reconstructed volume using offresonance correction are shown for different trajectories. Note the reduced signal attenuation in areas of strong susceptibility (bottom row). With an optimized trajectory (N=25/α=45°) an fMRI time series was acquired using visual stimulation. The resulting T-map (corrected threshold 4.1) as an overlay on a single time frame is displayed in Fig.5.

Discussion: We present a method that allows the design and optimization of 3D single shot trajectories based on a radial arrangement of individual petals. Optimization is performed with respect to the width and the total broadening of the PSF. Measurement of the actual PSF by applying single voxel excitation yields very good agreement with the results from the simulation. Compared to a fully encoded 3D GRE sequence (2min) the PSF of an optimal RIP trajectory with an acquisition time of 19.3ms shows only a moderate increase in width and global smearing. Compared to the ‘conventional’ rosette trajectory it has a narrower PSF and no visible sidelobes. Because of the reduced acquisition time it is less sensitive to field inhomogeneities as demonstrated in the last row of Fig.4.

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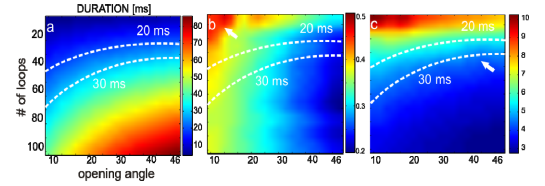


Fig.1) PSF simulations for different N and alpha, a) duration b) intensity in neighbour voxels c) ||PSF||²-1

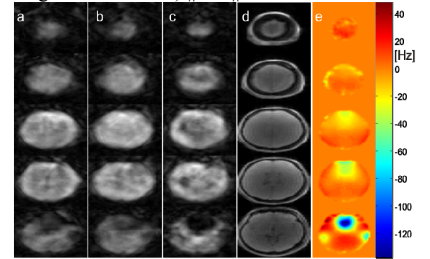


Fig.4) 5 slices from reconstructed volume: a) N/α=25/45, b) N/α=20/40; c)3D rosette; d) 3D GRE, e) field map

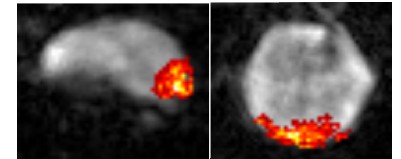


Fig.5 Basal visual activation: corrected T-threshold 4.1, glass brain overlay on reconstruction (acq=19.3ms), TR=100ms

petals N	α	time [ms]	width	PSF ²
20	40	16	0.35	5.8
25	45	19	0.30	5.4
40	15	19	0.28	5.1
35	35	26	0.37	4.98
3D-Rosette		23	0.47	6.1
cartesian		3min	0.11	.9