Parallel excitation pulse design using Bayesian inference theory

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Introduction:

One of the most promising technological developments of recent years is the extension of parallel imaging from the receive case towards spin excitation with transmit arrays (1,2). Most importantly, parallel transmission holds promise for achieving improved excitation homogeneity (which is particularly important at high field MRI with increased RF wave interference effects), reduced pulse length for lengthy multi-dimensional selective excitation, reduction of the specific absorption rate (SAR) (2) and mitigation of B0 induced blurring (3,4).

In this work a novel parallel transmit pulse design framework based on Bayesian inference theory is presented, which enables the incorporation of prior knowledge in a comprehensive fashion. In addition to numerical Biot-Savart simulations, preliminary experimental results of parallel transmission at 3T are presented.

Theory and Methods:

Bayesian inference is known as a general framework, which permits improving the solution of an inverse problem by incorporating existing prior knowledge about the problem. Hereby, the major measurement model and the prior knowledge are put on equal footing by expressing them as individual likelihood functions. The optimal solution of the inverse problem is then found by minimization of the product of the overall likelihood functions. For instance in the case of parallel receive, it can be shown that this framework leads to the well known, SNR-optimized SENSE reconstruction formulae (5).

In the small tip angle regime of parallel excitation, there exists a linear mapping **A**, between the desired excitation profile $\mathbf{m}_{des}$ and the required individual RF waveforms $\mathbf{b}_{full}$ (4). Hence the spatially weighted deviation Δ between $\mathbf{m}_{des}$ and the model can be expressed as:

$$\Delta = (m_{des} - Ab_{full})^H C^{-1} (m_{des} - Ab_{full}), \qquad [1]$$

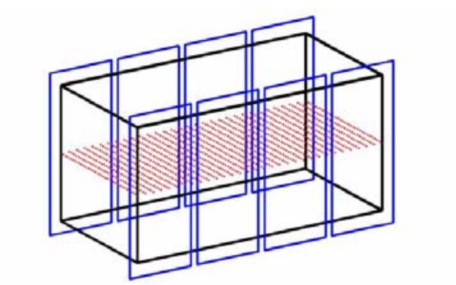

Figure 1:Eight-element parallel transmit, simulation setup.

with the covariance **C** specifying the degree to which a local variation from $\mathbf{m}_{des}$ is acceptable. On the other hand a prior may be identified that enforces minimization of the averaged SAR. Assuming **E** describes the linear mapping between $\mathbf{b}_{full}$ and the RF electric field, the SAR can be expressed according to:

$$SAR = b_{full}^H E^H Q^{-1} E b_{full} \qquad [2]$$

with the covariance **Q** describing the voxel volume and conductivity. Assuming a Gaussian distribution for the model deviation Δ as well as the prior, the overall likelihood function is given as:

$$\exp\left(-\frac{(m_{des} - Ab_{full})^H C^{-1} (m_{des} - Ab_{full})}{2} \right) \exp\left(-\frac{b_{full}{}^H E^H Q^{-1} E b_{full}}{2} \right) \qquad [3]$$

The minimization of this function leads to optimal RF waveform b_{full}^{opt} and its covariance Ψ:

$$b_{full}^{opt} = \Psi A^H C^{-1} m_{des}, \quad \Psi = \left(A^H C^{-1} A + E^T Q^{-1} E \right)^{-1}. \qquad [4]$$

Besides, SAR additional priors such as RF waveform smoothness can easily be incorporated into this framework.

The Bayesian parallel transmit framework has numerically been tested for a simulated setup consisting of a cuboidal object surrounded by eight rectangular transmit coils as shown in Fig. 1. Hereby, the transmit sensitivities, as well as the electric fields, have been calculated using quasi-static Biot-Savart integration (6).

Furthermore practical experiments have been carried out using a 3 Tesla GE Signa Excite HD system using a dedicated 4 element transmit array.

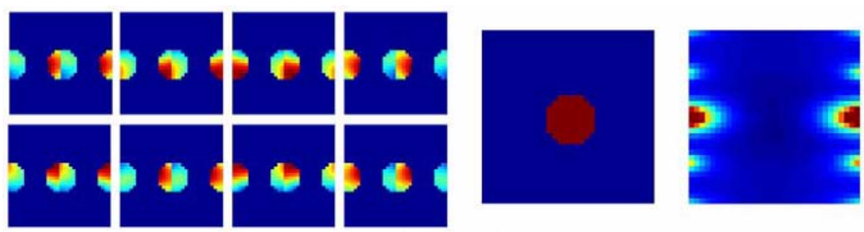

Figure 2: Individual coil excitations (left), Parallel excitation using all 8-elements simultaneously (middle), Local SAR distribution (right).

Although principally the framework is applicable for arbitrary k-space trajectories only Cartesian fly-back sampling has so far been investigated. For an excitation matrix size of 32x32, a field-of-view of FOV=20cm and a reduction factor of R=2 the RF pulse length was 8.2ms.

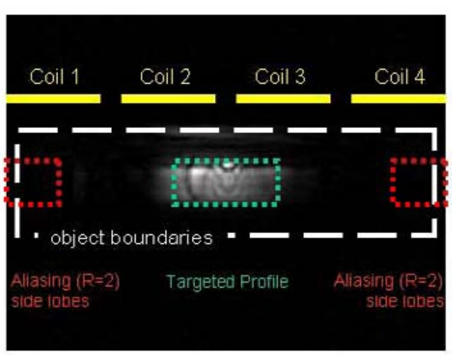

Figure 3: Experimental parallel excitation results with R=2. In addition to the targeted excitation, the four coil locations, the aliasing side lobes as well as the object boundaries are schematically indicated.

Results and Discussion:

Figure 2 shows simulation results obtained for the setup shown in Fig.1 assuming a reduction factor of two. The individual-coil transmit excitation profiles are shown on the left. In simultaneous parallel transmission these profiles add up to the desired circular excitation pattern with destructive interference of unwanted aliasing side-lobes (Fig. 2 middle). The corresponding SAR distribution is shown on the right of Fig. 2.

Figure 3 shows preliminary experimental results in form of a 2D selective RF excitation pattern obtained using a Cartesian fly-back trajectory with a reduction factor of 2.

Practical experience now needs to be gained using coil arrays of defined geometry in order for simulation results to be directly confirmed.

References: (1) Katscher U., et al, MRM 49: 144-150 (2003). (2) Zhu Y., MRM 51: 744-784 (2004). (3) Ullmann P., et al, MRM 54: 994-101 (2005). (4) Grissom W., et al, ISMRM Miami: p.19 (2005). (5) MacKay D.J.C., ‘Information Theory, Inference, and Learning Algorithms’, Cambridge University Press, Chapter 46, p. 549. (6) Roemer P.B., et al, MRM 16: 192-225 (1990).

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