Autocalibrated Accelerated Parallel Excitation (Transmit – GRAPPA)

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Introduction

Recently, parallel imaging techniques for accelerated volume-selective excitation with transmit-arrays have been proposed [1]. To date, these methods have all corresponded to image space based receive parallel imaging methods. One central problem in these methods is the accurate determination of the transmit sensitivities of the individual coils. This is especially difficult at high fields where the transmit field may differ significantly from the receive fields. Determination of the individual RF waveforms from the transmit sensitivities is an inverse problem, which is not easy to solve. In this abstract we show that autocalibration techniques such as GRAPPA [2] can be used to improve the performance of accelerated volume-selective excitation without the need to explicitly determine transmit sensitivities.

Theory

Volume-selective excitation is achieved by combining a modulated gradient with the application of an RF waveform corresponding to the spatial frequency spectrum of the desired excitation profile. Parallel imaging techniques achieve acceleration by using an undersampled excitation trajectory with a transmit array while appropriately modulating the individual RF waveforms to achieve the same excitation profile. In Transmit-GRAPPA the missing transmit segments are expressed as linear combinations of the pulse along one single segment. The output pulse for each coil is then given by the linear combination of these different segments expressed along the output segment.

Let the modulation of the object magnetization $M(\vec{x})$ caused by the RF waveform $\sigma(\vec{k})$ in coil *c*, *c* = 1…*C*, be $T_c(\vec{x})$, where $\vec{x}$ is the spatial coordinate, and $\vec{k}$ the excitation spatial frequency coordinate. The spatial frequency representations of these fields are $m(\vec{k})$ and $t_c(\vec{k})$, respectively, $\vec{k}$ being the receive spatial frequency coordinate. Assume also an array of *D* receive coils with sensitivity patterns $R_d(\vec{x})$ or $r_d(\vec{k})$, *d* = 1…*D*, and a desired acceleration factor *AF*. The *k*-space trajectory of $\sigma(\vec{k})$ is then subdivided into *AF* segments $\sigma^n(\vec{k})$, *n* = 1…*AF*, quite analogously to the receive parallel imaging case, e.g., skipping *AF*-1 *κ*-space lines for every transmitted one in a Cartesian experiment. The modulation of the object magnetization caused by $\sigma^n(\vec{k})$ in coil *c* is then denoted as $T_c^n(\vec{x})$ or $t_c^n(\vec{k})$. It is furthermore assumed that $\sigma(\vec{k})$, simultaneously used for all transmit elements, produces a maximally homogeneous combined transmit sensitivity, or a corresponding modulation $T^n(\vec{x})$ for one segment and $T(\vec{x})$ for all segments, with k-space representations $t^n(\vec{k})$ and $t(\vec{k})$, respectively given by:

(1) $T^n(\vec{x}) = \sum_{c=1}^{C} T_c^n(\vec{x})$, $T(\vec{x}) = \sum_{n=1}^{AF} T^n(\vec{x})$

The signal $s_{c,d}^n(\vec{k})$ received in receive coil *d* after transmission of $\sigma^n(\vec{k})$ in transmit coil *c*, ignoring relaxation, can then be expressed as

(2) $s_{c,d}^n(\vec{k}) = m(\vec{k}) * t_c^n(\vec{k}) * r_d(\vec{k})$ (operator $*$ denotes convolution in the *k*-domain)

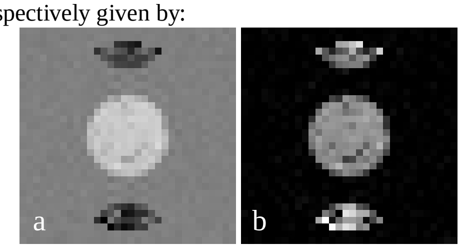

Figure 1: Real part of the object modulation from the odd (a) and even (b) lines of the excitation trajectory used for calibration.

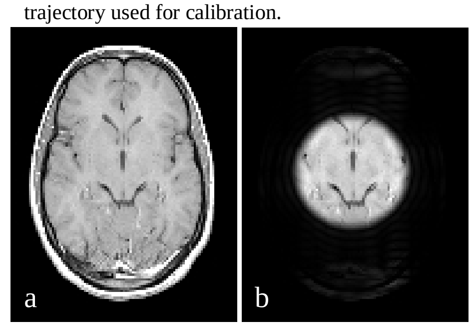

Figure 2: Simulation object with homogeneous (a) and accelerated volume (b) excitation.

Materials and Methods

Finding the desired RF waveform to play out simultaneously in the *C* transmit coils along the *n* = 1 excitation *k*-space trajectory for full excitation can then be found using the following algorithm:

- Transmit with each coil individually along segment $n = 1$ and receive data $s_{c,d}^1(\vec{k})$ simultaneously with all receive coils along the same *k*- / *κ*-space trajectory used for excitation
- Transmit with all transmit coils simultaneously along the other RF trajectory segments n = 2…*AF* and receive data $s_d^n(\vec{k})$ simultaneously with all receive coils yielding

  (3) $s_d^n(\vec{k}) = m(\vec{k}) * t^n(\vec{k}) * r_d(\vec{k})$
- Find scalar coefficients $f_c^{1\to n}(p,q)$, *n* = 2…*AF* such that

  (4) $\sum_{c=1}^{C} \sum_{p,q} f_c^{1\to n}(p,q) \cdot s_{c,d}^1(\vec{k} - p \cdot AF \cdot \Delta\vec{k}_y - q \cdot \Delta\vec{k}_x) = s_d^n(\vec{k})$,

  e.g., with $p \in$ [-1…1] and $q \in$ [-2…2]. During accelerated excitation, transmit $\sigma_c^1(\vec{k})$ with all coils *c* = 1…*C* simultaneously along trajectory *n* = 1 with

(5) $\sigma_c^1(\vec{k}) = \sum_{n=1}^{AF} \sum_{p,q} f_c^{1\to n}(p,q) \cdot \sigma^1(\vec{k} - p \cdot AF \cdot \Delta\vec{k}_y - q \cdot \Delta\vec{k}_x)$,

using the same *p* and *q* ranges as in eqn. 4. The signal $\hat{s}_d^1(\vec{k})$ acquired after accelerated excitation can be shown to be the same signal as produced by the original $\sigma(\vec{k})$ without acceleration.

Results

Using the autocalibration approach, only a few *k*-space lines on the receive side have to be acquired in the calibration phase. A simulation of this is shown in Figure 1, which shows the low resolution images used for calibration for an acceleration factor of 2 using an 8 element birdcage-like array for transmission. In this case, images of size 32x32 were used for determination of the linear combination coefficients. As can be seen in Fig.2, the resulting profile corresponds quite well to the desired circular-shaped profile.

Conclusion

A simple method for acceleration of multidimensional RF pulses using parallel transmission has been developed based on the GRAPPA formalism. Using this concept, it is possible to derive the RF pulses for the individual coils using an autocalibrated approach, so that no absolute quantification of the transmit profiles of the individual coils is required. All that is required for a *C* coil setup is *C* acquisitions in which a single segment is transmitted with a single coil and received with all coils followed by *AF-1* acquisitions in which the other segments are transmitted and received in all coils. Since all of these acquisitions can be low resolution experiments, this process should be fast and can therefore easily be repeated for different slice locations or pulse shapes. This should be especially useful at high field strengths where the profiles of the transmit fields are significantly different than the receive fields and may be more sensitive to loading changes during the experiment.

References: [1] U. Katscher, *et al.*, *MRM* **49**(1):144-50 (2003) [2] M.A. Griswold, *et al.*, *MRM* **47**(6):1202-10 (2002)