RF Excitation Using Time Interleaved Acquisition of Modes (TIAMO) to Address B1 Inhomogeneity in Highfield MRI

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Introduction

As the field strength and therefore the operational radiofrequency (RF) in MRI is increased, the RF wavelength decreases and approaches the size of the human head/body resulting in RF wave effects which cause signal decreases and dropouts in 7T and also in 3T body MRI applications. Several multichannel approaches have been proposed to try to tackle these problems, including RF shimming (1), where each element in an RF transmit array is driven by its own amplifier with a certain (constant) amplitude and phase, and Transmit SENSE (2), where spatially tailored RF pulses are used. Here we propose a novel method based on multiple transmit modes.

Theory

For a single receive coil m in conventional imaging, the spatial distribution of the signal S received by this coil m at location $\mathbf{r}$ when using a set of phases and amplitudes (“mode”) n for the transmit elements in a long repetition time (TR) and short echo time (TE) gradient echo sequence using a simplified small-tip-angle approximation (3) can be approximated as

$$S_{m,n}(\mathbf{r}) \propto \hat{B}_{1,m}^{-}(\mathbf{r}) i\gamma W(\mathbf{r}) \int_0^T \hat{B}_{1,n}^{+}(\mathbf{r},t) e^{i\mathbf{r}\cdot\mathbf{k}(t)} dt \qquad [1]$$

In this expression, W is the tissue-dependent weighting factor; $\hat{B}_{1,n}^{+}$ and $\hat{B}_{1,m}^{-}$ are the complex circularly-polarized components of the B_1 field, with $\hat{B}_{1,n}^{+}$ being the time-dependent combined transmit field of all coils in mode n and $\hat{B}_{1,m}^{-}$ being the receive field of coil m; γ is the gyromagnetic ratio; T is the duration of the B_1 pulse; and $\mathbf{k}(t)$ parametrically describes a path through k-space.

The spatial dependencies of $\hat{B}_{1,n}^{+}$ and $\hat{B}_{1,m}^{-}$ can be described using spatial weighting factors. Since for a given mode n the spatial dependence is time independent, the weighting factors can be combined to form a single weighting factor $C_{m,n}(\mathbf{r})$:

$$S_{m,n}(\mathbf{r}) \propto C_{m,n}(\mathbf{r}) \hat{B}_1^{-} i\gamma W(\mathbf{r}) \int_0^T \hat{B}_1^{+}(t) e^{i\mathbf{r}\cdot\mathbf{k}(t)} dt \qquad [2]$$

This equation implies that using two different coil excitation modes in separate acquisitions is mathematically equivalent to performing one acquisition with twice the number of receive elements, each with a different reception profile. The mode excitation leads to the formation of “virtual" receive elements. Since the datasets are acquired at different time intervals, there is no noise correlation between them. Although the above derivation strictly holds only in the small-tip-angle regime for long TR and short TE, our experimental results indicate that the approach also works acceptably well with high flip angles and short repetition times.

Materials and Methods

All scanning was performed on a 7 Tesla whole-body MR scanner (Magnetom 7T, Siemens, Germany). For time-interleaved acquisition, two sets of phases with constant amplitudes were buffered in an 8-channel vector modulator of a custom-built 8-channel RF shimming system (4). The first set had a phase increment of 45° from one element to the next, the second set had a phase increment of 90°. Two datasets were acquired in an interleaved manner: After each acquisition line (or echo train) of the first dataset, the same acquisition line (or echo train) for the second dataset was acquired. The two data sets were then reconstructed in 3 ways using openGRAPPA (5): Just the Birdcage (BC) mode (45° phase increment between elements), each mode separately with subsequent combination using sum of squares (SoS), and lastly both modes together using 16 virtual channels (TIAMO).

For SNR and g-factor measurements, an 8-channel T/R head coil was used on a 12-cm-Ø cylindrical phantom filled with tissue-simulating liquid ($\varepsilon_r = 46.3$, $\sigma = 0.8\ \Omega^{-1}\ \mathrm{m}^{-1}$). A turbo spin echo sequence with a TR of 3000 ms and a TE of 59 ms was acquired twice to determine SNR with a dual acquisition and subtraction method. In vivo measurements were performed with an 8-channel flexible T/R-array and a FLASH sequence with a TR of 10 ms and a TE of 4.1 ms.

Results and Discussion

Figure 1 shows the SNR distribution for each of the 3 reconstructions. TIAMO and SoS are clearly more homogeneous than the BC mode.

The measured mean SNR in an axial slice of the cylindrical phantom is plotted in Figure 2. It is clearly visible that higher acceleration factors are possible with TIAMO, and the time penalty for acquiring two modes can be substantially reduced.

T1-weighted in vivo images in a human volunteer are shown in Figure 3. The individual signal voids in the two separate modes (arrows) are clearly visible, but they are almost completely gone in the TIAMO images in the right column. It is important to note that since the B_1 is non-uniform in each of the individual modes, the contrast in the final image is expected to deviate from an image acquired with a uniform B_1 field. This would appear to make TIAMO unsuitable for most quantitative imaging, but for clinical diagnostic imaging in highfield body MRI, TIAMO is an attractive new alternative to other ways of mitigating signal dropouts.

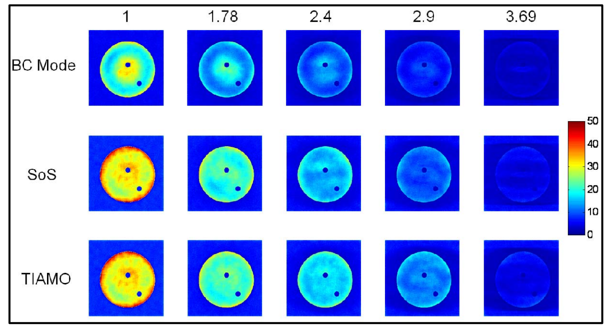

Fig. 1: SNR maps of a cylindrical phantom for different effective reduction factors.

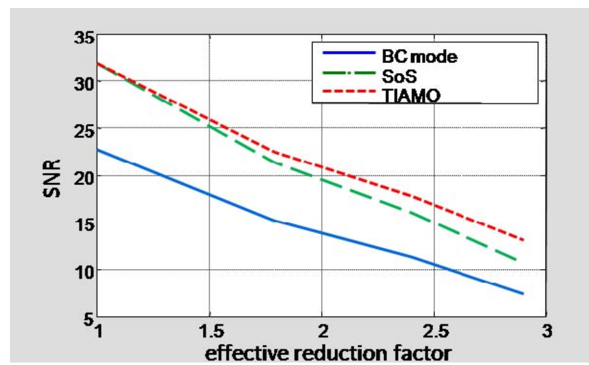

Fig. 2: Measured mean SNR versus effective reduction factor in a cylindrical phantom in an 8ch head coil for the Birdcage mode (**BC-mode**), Sum of Squares (**SoS**), and **TIAMO**.

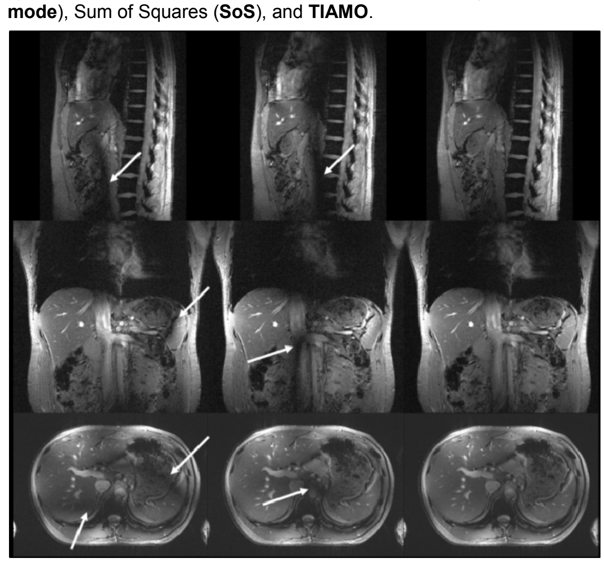

Fig. 3: Sagittal, coronal, and axial in vivo T1-weighted images of a human volunteer (1.78 m, 75 kg). From left to right: 45° phase increment, 90° phase increment, TIAMO. Note the markedly improved signal homogeneity in the TIAMO images.

References: [1] Collins et al. MRM 54:1327-1332, (2005); [2] U. Katscher et al. MRM 49:144-150, (2003); [3] J. Pauly et al. JMR 81:43-56, (1989); [4] A. Bitz et al. Proc. Intl. Soc. MRM 17:4767 (2009); [5] M. A. Griswold et al. MRM 47:1202-1210, (2002)