Improved Navigator Performance by Parallel Transmission

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Introduction

Parallel transmission has gained considerable interest during the last few years [1, 2]. Multiple individual RF transmit coils have been introduced to overcome B_1 homogeneity limitations and to improve the performance of multi-dimensional RF pulses by shortening their duration. One of the simplest multi-dimensional RF pulses, used clinically, is the pencil beam [3] which finds application as a navigator to sense respiratory motion [4]. This 2D RF pulse is based on a spiral gradient trajectory exciting basically the point spread function (PSF), the most elementary excitation pattern of this class of RF pulses, making it also interesting for theoretical studies. In clinical applications, especially in cardiac MR, a compromise has to be found between the spatial resolution of the navigator, i.e. the beam diameter and the extent of the excitation FOV (FOX). Both are defined so as to suppress unwanted signal contribution and are linked to the RF pulse duration. A long navigator pulse would allow for excellent background suppression but would make the RF pulse very prone to off-resonance effects, substantially degrading the desired spatial resolution. RF pulse shortening is desired especially at high field applications (3T and beyond) where main field inhomogeneities (cf.Fig.1.) and susceptibility induced effects substantially degrade navigator performance. In this work the use of parallel transmission as a means of coping with this problem is investigated. Different scenarios are studied theoretically and experimentally.

Methods

The spatial definition of the pencil beam navigator is achieved by gradient encoding using a spiral k-space trajectory [3]. Strong off-resonance, present especially near the liver-lung interface (cf.Fig.1.), results in serious blurring, degrading the performance for long pulses. RF pulse shortening can be achieved by replacing gradient encoding by transmit sensitivity encoding [1] suppressing unwanted aliasing artifacts. Three approaches have been investigated for an eight channel parallel TX system: In the first, Transmit SENSE was applied using different waveforms for each individual TX coil, assuming full system flexibility. The second approach uses only a single TX coil next to the desired beam position, while the third approach is similar to B_1-shimming using a fixed analytically derived RF waveform [4] for all 8 channels, but weighted appropriately by a complex factor. This approach is suitable for parallel transmit systems with slightly restricted functionality. To derive the corresponding RF waveform or channel weighting factors for the three approaches the following optimization problem [5] was solved iteratively in the spatial domain: $\mathbf{b} = \arg_{\mathbf{b}} \min\{||\mathbf{A}\mathbf{b} - \mathbf{M}_{\text{desired}}||^2 + \mathrm{R}(\mathbf{b})\}$.

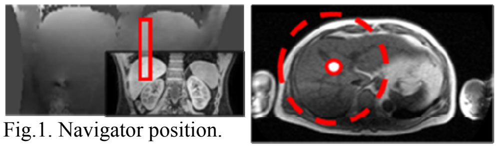

Fig.1. Navigator position. (right) Beam with potential aliasing ring, (left) coronal liver B_0-map (background) illustrating the frequency shift near the air-tissue interface (up to 5 ppm).

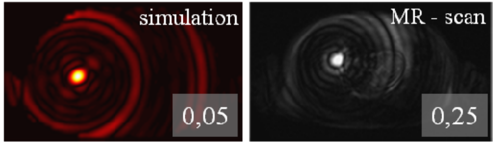

Fig.2. Results for a standard non-improved navigator with 4 revolutions (T_{pulse}: 1.7ms) using a birdcage-configuration neglecting coil sensitivity. Aliasing rings are clearly visible.

Here, $\mathbf{b}$ denotes the desired RF-waveforms (approach (1,2)) or the complex weighting coefficients (approach (3)); $\mathbf{A}$ denotes the encoding matrix comprising the individual coil sensitivities and the Fourier encoding term, and $\mathbf{M}_{\text{desired}}$ represents the desired magnetization pattern (the beam). To control RF-power a Thikonov regularization term $\mathrm{R}(\mathbf{b})$ was added. Simulations for all three scenarios were carried out in Matlab (mathworks) to verify the anticipated outcome prior to conducting in vivo experiments. All simulations and experiments were performed for and on a 3T parallel transmit system (Philips Achieva) equipped with an 8 TX-channel body coil [6]. For the pencil beam (Ø: 30mm) a variable angular speed spiral gradient trajectory was used with different numbers of revolutions and pulse durations (8 rev.: 3.5ms, 4 rev.: 1.7ms). For phantom and in vivo experiments (three healthy volunteers involved, informed consent obtained) low resolution B_1-maps (64×64, FOV $(480\text{mm})^2$) were acquired for all eight TX-channels using the actual flip angle (AFI) sequence in the “all-but-one”- mode [7]. These coil sensitivity data were also used in the simulations. To judge the performance a simple signal-to-background-ratio was used, which translates to the absolute magnetization response on-target (the beam) divided by the absolute magnetization response off-target. This approach proved to be the most reliable in terms of predicting navigator performance. All RF pulses were computed using a Dirac Delta shaped target on a 32×32 matrix. Navigator pulse performance was measured using a low tip angle gradient echo sequence (matrix: 128×128, FOV: $(480\text{mm})^2$, FOX: $(120\text{mm})^2$, TR 50ms), and navigator gating signals were obtained using a slightly modified sequence with a temporal resolution of 200ms in all volunteers. For comparison, experiments mimicking single body coil transmission using the birdcage mode were added.

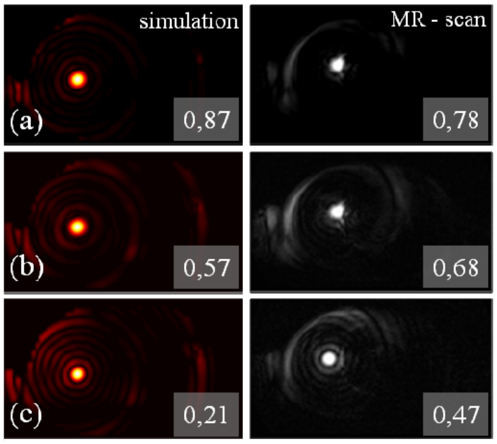

Fig.3. Different concepts for a 4 revolution navigator (T_{pulse}: 1,7ms). (a) 8-coil Transmit SENSE, (b) single, but nearest TX coil, (c) 8-coil B1-shimmed. The number in the lower right (a-c) gives the signal-to-background-ratio. The FOV is $(480\text{mm})^2$ and the FOX is $(120\text{mm})^2$.

Results and Discussion

Simulations and experiments showed that all three approaches deliver a significant improvement over the performance of a simple birdcage-mode navigator (cf.Fig.2.). In vivo results were in close agreement with the simulations. The 8-channel Transmit SENSE approach proved to perform best (cf.Fig.3a.), significantly improving respiratory gating signals (cf.Fig.4.). Using only the nearest coil approach (cf. Fig.3b), one has a notable alternative to the latter. However, beam positioning in this case has to be congruent with a high coil sensitivity in the region of interest to obtain good results. In general, parallel transmit concepts deliver improvements of at least a factor of 4 (cf.Fig.2-3) in terms of signal-to-background-ratio when compared with a single body coil. With a duration of only 1.7ms the navigator pulse is also very robust against resonance frequency mistuning. In addition to using parallel transmit configurations, it seems very promising to incorporate parallel receiving coils, hence benefitting from further artifact attenuation due to localized reception.

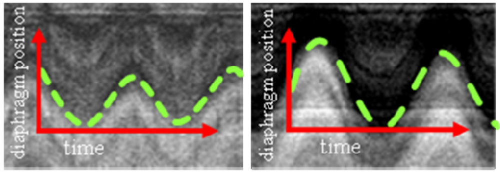

Fig.4. Comparison of respiratory navigator design using a single body coil in birdcage mode (left) and the 8-channel Transmit SENSE approach (right) showing the significantly reduced background level.

References:

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