Robust Compensation of Magnetic Field perturbations for Localized Spectroscopy Applications

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Introduction

Weak water suppression is used in some localized proton ([1]H) spectroscopy applications, so that a considerable amount of water signal remains and can be used for various purposes. In these cases the spectra might suffer from sidebands of residual water signal caused by coil vibrations. Various methods have been published previously [1-4] to eliminate these sidebands. But most of them do not meet the wide clinical requirements due to limited robustness, reduction of SNR or a complicated implementation and high costs. In this abstract, factors affecting the results of the sideband cancellation in opposite-gradient acquisition scheme [3] are analyzed. Based on this scheme, a robust and simple compensation method is presented, in which optimized cancellation is achieved by carrying out eddy-current phase correction for positive-gradient (PG) and negative-gradient (NG) acquisitions respectively.

Theory

The acquired FID signal of one specific chemical component (e.g. water signal) can be expressed as:

$s(t) = A(t) \cdot exp(\, j \cdot (\varphi_0 + \varphi_f(t) + \varphi_{\Delta f}(t) + \varphi_{EC}(t) + \varphi_{vibration}(t)))$ [1]

Where $A(t)$ and $\varphi_f(t)$ are the amplitude and the ideal phase of the signal. φ_0 is a constant phase offset. $\varphi_{EC}(t)$ and $\varphi_{vibration}(t)$ represent the phase perturbations caused by eddy currents and the vibration or oscillation of the magnetic field respectively. $\varphi_{\Delta f}(t)$ denotes the additional dephasing due to the intravoxel static field inhomogeneity.

Due to eddy currents, amplitude and line shape of the water signal will be changed when the polarities of all gradients are inversed, which will also cause the corresponding changes in sidebands. As a result, the sidebands can not be cancelled completely by complex averaging of the signals acquired with sequences using opposite gradients. Even worse, the interesting signal from metabolites might be cancelled due to the eddy current effect. For this reason, removing the eddy current effect before signal averaging is necessary.

Methods

Figure 1 shows the improved scheme to compensate the vibration-related magnetic field perturbations. The localized spectroscopy sequence is adapted like this: A total of N averages is divided into two groups. The second half of the averages comprising all the gradients including spoilers and slice-selective gradients comes along with an opposite polarity compared to the first half of averages. Two reference scans - one for the positive and one for the negative gradient mode - without RF pulses for water suppression [5] are done after the eddy current has reached a steady state.

Assuming the transmitter frequency is on water resonance, the total phase modulation of reference scans in the time domain can be decomposed into two contributions:

$\varphi_{ref}(t) = \varphi_N(t) + \varphi_P(t)$ [2]

whereby $\varphi_N(t) = \varphi_0 + \varphi_{\Delta f}(t) + \varphi_{EC}(t)$ denotes the low-frequency and non-periodic phase modulations, and $\varphi_P(t) = \varphi_{vibration}(t) + \varphi_m(t)$ denotes the relatively high frequency periodic modulations including the phase perturbations from gradient coil vibrations and the phase of metabolite signals $\varphi_m(t)$. Although it was mentioned in [5] that the phase of metabolite signal could be ignored for reference lines, we still consider it for consistency. A low-pass filter is applied on reference lines in the time domain to eliminate $\varphi_P(t)$. A sliding average filter is used as it provides an excellent performance for the suppression of periodic noise [6]. The length of the sliding window is set to approximately $1/(f_{vibration} \cdot \Delta T)$, where $f_{vibration}$ is the mechanical vibration frequency of the gradient coil and can be fixed for each system,while ΔT is the sampling interval in the time domain.

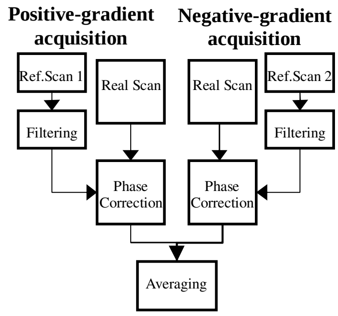

Figure 1. The data acquisition scheme to compensate the vibration-related magnetic field perturbations

In the phase correction step, $\varphi_N(t)$ can be eliminated from the real-scan data by subtracting the phase of filtered reference lines from that of the real-scan data in the time domain. This step is done for PG and NG acquisitions separately. With phase correction, the effects of eddy currents as well as intravoxel static field inhomogeneities are partly removed from the real-scan data. As a result, the sidebands can be cancelled by averaging the phase-corrected data in the final step.

Experiments were performed on three 1.5T MRI systems (pre-industrial prototypes) with different gradient performances and field homogeneities. To obtain $f_{vibration}$, an experiment with a water phantom was done on every system yielding the uncompensated MR spectrum from which $f_{vibration}$ could be estimated by counting the frequency distance between the peak of the water signal and the first sideband close to it. After that, both phantom and in-vivo experiments were performed on all three systems to evaluate the improved compensation scheme. Different sample positions including iso-center and off-center and volumes with different sizes were tested. TE= 30 ms and weak water suppression were used in all experiments.

Results

Figure 2 shows examples of the experiments' results. Due to limited space, only a part of the water signal is displayed. The uncompensated phantom spectrum (a) and in-vivo brain spectrum (d) are distorted by eddy-current effects, sidebands are visible (arrows) and one of the metabolite signal peaks (arrow on the right) in (d) is contaminated by the sideband. The corresponding compensated spectra (c,e) created by the optimized opposite-gradient acquisition scheme, however show good qualities and a higher resolution with both sidebands and eddy-current effects absent. While the spectrum in (b) compensated by the original opposite-gradient acquisition scheme still has visible sidebands (arrows). The results from all experiments on the three systems showed that the optimized compensation scheme can suppress the vibration-related sidebands of water signal to under noise level and eliminate the eddy-current effect as well as improve the line shape and SNR, thus demonstrating the robustness of this optimized scheme.

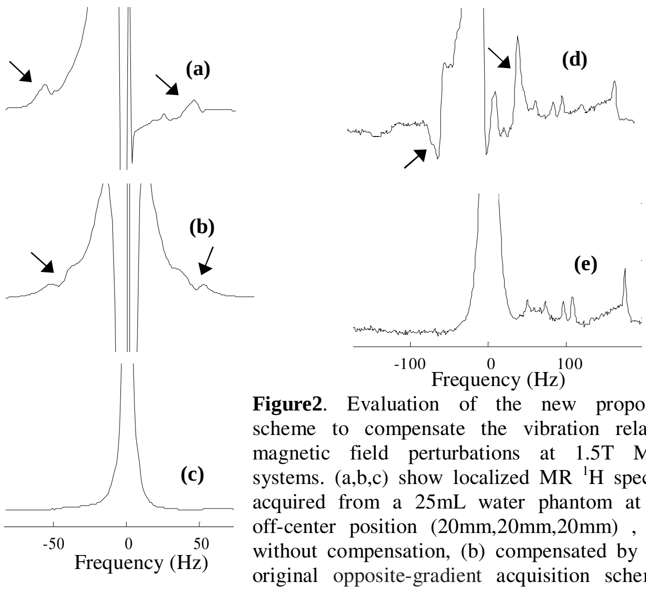

Figure2. Evaluation of the new proposed scheme to compensate the vibration related magnetic field perturbations at 1.5T MRI systems. (a,b,c) show localized MR [1]H spectra acquired from a 25mL water phantom at an off-center position (20mm,20mm,20mm) , (a) without compensation, (b) compensated by the original opposite-gradient acquisition scheme. (c) compensated by the improved opposite-gradient acquisition scheme. (d,e) show localized MR [1]H spectra from the human brain, (d) without compensation, (e) compensated by the improved opposite-gradient acquisition scheme.

Discussion

The optimized compensation scheme has been shown to be efficient in eliminating the frequency modulation sidebands in localized [1]H spectroscopy with weak water suppression. For application without water suppression, this compensation scheme should be adapted, which will be our future work.

Reference

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