SNR improvement of MR phased array spectroscopy signals

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Introduction

It is well known that surface coil arrays can increase the signal-to-noise ratio (SNR) in magnetic resonance spectroscopy (MRS) studies by performing a proper combination of the individual signals. Although it has been shown that electric and magnetic coupling mechanisms produce correlated noise in the coils [1], previous algorithms developed for MRS data combination have ignored this effect. In this work we describe a novel method for the combination of MRS signals acquired by a phased array coil taking into account possible noise correlations. Performance evaluation was carried out on simulated ^{1}H-MRS signals and preliminary experimental results were obtained on phantom ^{1}H-MR spectra.

Materials and Methods

The model of FID signal used to simulate, in the time domain, the MRS signals acquired by a phased array is the following:

$$x_m(t) = s_m e^{j\varphi_m} \sum_k a_k e^{j\vartheta_k} e^{(-d_k + j2\pi f_k)t} + \varepsilon_m(t) \quad \text{with } m = 1,\ldots,M \qquad (1)$$

where M is the number of coils, $\varepsilon_m(t)$ is a complex Gaussian noise term, and a_k, θ_k, d_k, f_k, denote respectively the amplitude, phase, damping factor and frequency of the k-th sinusoid. The gain factor s_m takes into account the amplitude variations due to the different sensitivity of each m coil, while $e^{j\varphi m}$ is the phase shift dependent on the receiver position. To perform a realistic simulation, we estimated s_m and $e^{j\varphi m}$ from the B_1 field distribution of an 8-element RF coil array consisting of two 2 x 2 grids of square coils. Each element was 14 x 14 cm and the elements were gapped by 1.5 cm in the left-right direction and overlapped in the foot-head direction. Biot-Savart equation was used for the simulation of B_1 field distributions of the coils in the y-plane between the two grids (see Fig. 1). Noise correlation effect was also introduced in the model by mixing M circular complex white noise sources $\acute{\varepsilon}$ as follows: $\boldsymbol{\varepsilon} = [\mathbf{A}+\alpha\mathbf{I}]\acute{\boldsymbol{\varepsilon}}$, where $\mathbf{A}$ is a square MxM matrix with non-zero elements off the diagonal, α is a multiplication factor used to change the degree of correlation between channels and $\mathbf{I}$ is the unitary matrix. Noise correlation values have been chosen according to those experimentally found from overlapping coil acquisitions [2].

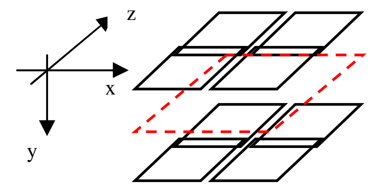

Fig. 1 Coil position and FOV.

Generally, the combined MR spectrum x_c is given by the weighted summation of the individual signals x_i of the phased array

$$x_c = \sum_{i=1}^{M} w_i x_i = \sum_{i=1}^{M} |w_i| e^{j\varphi_i} x_i \qquad (2)$$

where w_i are complex weighting factors. Here we propose to include in the combination method a preprocessing stage designed to decorrelate the noise between channels with the aim to project the MRS signals onto a subspace where the metabolite information adds coherently, while the noise adds incoherently [3]. To do this, we firstly estimated the noise covariance matrix $\boldsymbol{C}_\varepsilon$ employing the last time points of the FID signal as noise. Then from the eigendecomposition of $\boldsymbol{C}_\varepsilon$ we obtained the whitening transformation $\boldsymbol{V} = \boldsymbol{D}^{-1/2}\boldsymbol{E}^T$, where $\boldsymbol{D}$ is the diagonal matrix of the eigenvalues and $\boldsymbol{E}$ is the matrix of the eigenvectors. Finally, we projected the original signals x_m onto the subspace described by $\boldsymbol{V}$, thus obtaining a new set of channels with no noise correlations. On these noise decorrelated signals we performed the two typical operations involved in the optimal combination of MR phased array signals: the phasing and the weighted summation of Equation (2). The complex weighting factors w_i were calculated using the procedure described in [4]. To investigate the performance of the proposed method, a Monte Carlo simulation was performed varying the voxel positions and the noise power and correlations. Experimental studies were performed using a 1.5T scanner (Signa Excite General Electric , Waukesha, WI, USA) with a phased array surface coil as RF receiver. A phantom, consisting on a clear plastic box of 25x14x35 cm^3 (x,y,z) with a water solution of 15mM creatine and 5.6mM choline, was used. PRESS sequence (TE 35 ms, TR 2500 ms) was used to acquire spectra from voxels of dimensions 2x2x2cm^3.

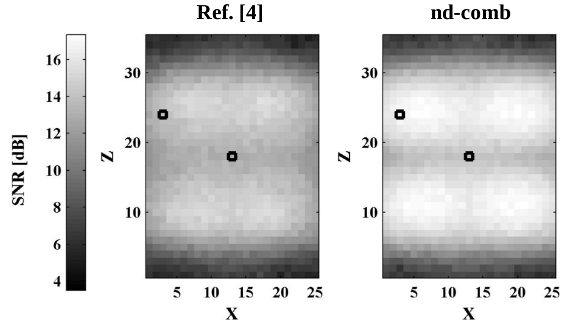

Fig. 2 Comparison of the SNR spatial distribution.

Results and Discussion

We compared the performance of the proposed method, referred to as "nd-comb" (noise decorrellated combination), with the method developed in [4], which is one of the most employed by research community, by evaluating the SNR of the combined spectrum. Fig. 2 depicts the spatial distribution over the FOV of the SNR achieved in the Monte Carlo simulation by the two compared combination methods. According to our results, nd-comb attained higher SNR values than Ref. [4] over the considered FOV. In addition, the SNR improvement, in the central and in the peripheral voxel (indicated by the squared boxes in Fig. 1), obtained by the proposed method as a function of the noise power and the noise correlations is shown in Fig. 3. In particular, as the level of noise correlations (ρ_{noise}) increased the SNR gained by nd-comb largely outperformed those gained by Ref. [4], thus demonstrating its effectiveness in destroying noise correlations and enhancing the metabolite signals. Concerning phantom acquisitions, although the observed noise correlations were rather low (<0.2 between adjacent coils), we found a fair increase (about 5%) of the SNR in the peripheral voxel, whereas in a central voxel the contrasted methods obtained the same results.

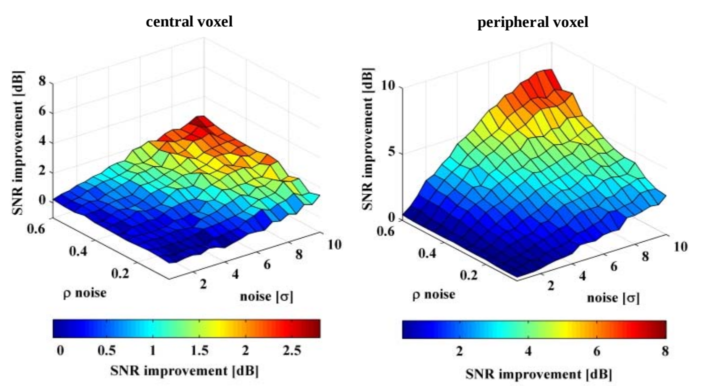

Fig. 3 SNR improvement as a function of noise power and correlations.

Conclusion

In summary, we developed and investigated the performance of a novel method for the combination of MRS signals acquired by phased array. Simulation results demonstrated the effectiveness and the robustness of the proposed method, especially as the noise correlations between coils increased. Although in phantom measurements we observed relatively low correlation values, our approach could be usefully applied in high density phased arrays, since it has been shown that noise correlations become not negligible when number of coil elements increases [5].

References

[1] Roemer PB et al. *Magn Reson Med* 16(2):192–225. [2] De Zanzhe N et al. *NMR Biomed* 21(6):644–654. [3] Martini N et al. IET MEDSIP 2008. [4] Prock T et al. *Phys Med Biol* 47(2):N39–N46. [5] Schmitt M et al. *Magn Res Med* 59:1431–1439.