Adaptive Signal-Preserving Denoising of ER-fMRI Data Using Spectrum Subtraction

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Introduction

Event-related Functional magnetic resonance imaging (ER-fMRI) data suffer from interferences due to a variety of sources [1]. Among those sources is random noise, which is rather challenging to remove. In particular, the methods that can be used to remove the noise must remove only the random component of the signal without distorting the true signal in any form. This is difficult in practice because of the inherent low-pass filtering of the noise removal techniques, which tend to smear the high frequency components of the true signal. In this work, a new noise suppression method based on spectrum subtraction is introduced. This method is a modified version of a well-established speech enhancement method [2] and has the advantage of ensuring that the true signal is preserved. The proposed method is applied to simulated data as well as data from an event-related fMRI study where the signal-to-noise ratio is rather low. Results show dramatic reduction of random noise in both cases.

Theory

Generally speaking, the fMRI temporal signal can be modeled as the summation of the true activation signal, a physiological noise component, and a random noise component. The physiological noise component can be considered as a deterministic yet unknown signal. Hence, it can be suppressed using harmonic modeling [1]. Therefore, we will consider a model that is composed of the sum of one deterministic component incorporating both the true signal and the physiological noise and an uncorrelated stochastic component. That is,

$s(t)= d(t) + n(t)$.				(1)

Then, their power spectra can be computed as:

$Pss(w)= Pdd(w)+ Pnn(w)$,			(2)

where the cross terms vanish because the two components are assumed uncorrelated. Hence, an estimate of the power spectrum of the deterministic component can be obtained as,

$P_{dd}(w)= P_{ss}(w) – P_{nn}(w)$,			(3)

with the negative power spectrum values set to zero.

Given the practical constraints of limited temporal length of the signal, the spectra in (3) are replaced by windowed estimates of the respective quantities. In this paper, we use the square of the Fourier transform as the periodogram estimate of the power spectrum.

In order to recover the deterministic signal component from its power spectrum, only the magnitude of the Fourier transform can be obtained as the square root of the power spectrum. The phase component cannot be recovered directly from the power spectrum. Alternatively, the phase is estimated as the phase of the Fourier transform of the original signal. In a mathematical form,

$D_e(w) = (P_{dd}(w))^{1/2}\ \mathrm{Exp}(j\ \mathrm{Phase}(S(w))$

Then, the enhanced deterministic signal is just the inverse Fourier transform of this estimate. As can be observed from the formulation of the technique, the correlated noise and distorting filtration encountered in other noise reduction techniques are not present here because of the simple subtraction basis of the method.

Methods

A key issue to the success of the proposed technique is the adaptive estimation of the noise power spectrum. Two approaches can be used to characterize the present noise using parametric and non-parametric methods [3]. In this paper, we select a parametric technique where the available data from the time courses of pixels not showing activation (or from a baseline acquisition if available) are used to estimate the parameters of a white Gaussian noise model. This model has a simple to estimate uniform power spectrum, which yields an efficient computational load (only computing variance of data is needed).

To verify the new technique, event-related fMRI data from an activation study performed on a volunteer using a Siemens 1.5T clinical scanner were used. In this study, an oblique slice through the motor and the visual cortices was imaged using a T2*-weighted EPI sequence (TE/TR= 60/300 ms, Flip angle=55°, FOV=22cmx22cm, slice thickness=5 mm). The subject performed rapid finger movement cued by flashing LED goggles. The study consisted of 31 epochs, with 64 images per epoch. Temporal data from a single pixel in each of the motor and visual cortices are processed using the new method.

Results and Discussion

The results of applying the proposed method on the actual ER-fMRI data are shown in Fig.(2). As can be seen, a considerable qualitative improvement in the signal quality can be shown. The quantitative measurements using numerical simulations confirm this result. The "gold standard" method used in [4] was not used because of the presence of baseline variation from the physiological noise component. In conclusion, a new method for ER-fMRI signal denoising was developed and verified experimentally. The parameters used in this method are estimated from the processed data set and hence the technique adapts to different input SNR values. The proposed technique preserves the signal components while suppressing the noise. This suggests its use for preprocessing of fMRI data in a similar manner as [1] to improve the accuracy of data analysis.

References

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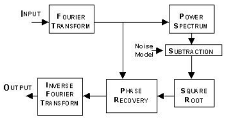

Fig.1 Block Diagram of the proposed method

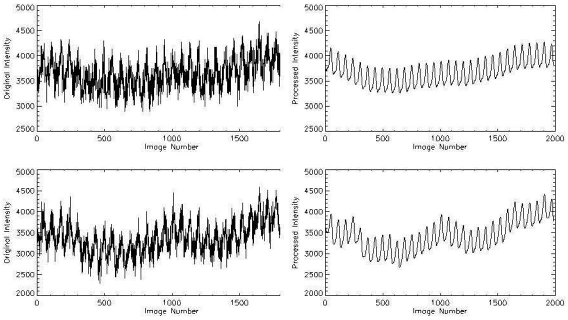

Fig.2 Time courses from two different pixels (left) and the resultant processed signals (right).