Physiological Noise Suppression for Functional Magnetic Resonance Imaging by Normalized Least Mean Square Adaptive Filtering

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Introduction

Functional magnetic resonance imaging (fMRI) has been widely employed as a noninvasive, radiation-free and high spatial-temporal resolution neuroimaging tool. However, interference could mask out the presence of functional activities owing to inherently low sensitivity of the functional signal. Examples include physiological noise due to cardiac or respiratory pulsation, which has been shown to cause signal fluctuations in certain brain areas. In this study, we propose the application of a normalized least mean square adaptive filter (NLMSADF) (3) for a suppression of the physiological noise using its learning nature.

Methods and Materials

NLMSADF (Fig.1) has been widely used for its computational simplicity. By minimizing the mean square error, the filter coefficient adaptation is given by:

W(n+1) = W(n) + (beta / ||R(n)||^2) * e(n) * r1(n)
e(n) = d(n) - y(n)
y(n) = W^T(n) * R1(n)
R1(n) = {r1(n), r1(n-1), ..., r1(n-N+1)}^T
W(n) = {w0(n), w1(n), ..., wN-1(n)}^T

where

- d(n): input signal, the combination of desired signal s(n) and primary noise r0(n).
- r1(n): reference noise, correlated with r0(n).
- W(n): NLMSADF's coefficients.
- e(n): the estimated desired signal s'(n) if s(n) is uncorrelated with r1(n).
- beta: convergence factor.

The convergence factor beta was determined empirically to be 0.02, and order of filter to be 7 in this study.

Simulation

The synthetic signal was constructed as follows:

S(n) = S_act(n) + Noise1(n) + Noise2(n)

where

S_act(n): activationsignal

Noise1(n): physiological noise. In this simulation, only respiratory noise was included.

Noise2(n): Gaussian white noise.

The reference noise is simulated to be proportional to the physiological noise. The SNR1,2, defined as the standard deviation of S_act over the standard deviation of Noise1,2, ranged from 1 to 4. For each SNR, 1000 repetitions were conducted to obtain the normalized noise power suppression defined by:

NNPS = (estimated Noise1 - Noise1)^2 / |Noise1|^2

MRI Experiment

Data from two healthy young male subjects were included. Single-slice gradient echo EPI was acquired repeatedly(400 time frames), with TR/TE=250/35ms, matrix x64, FOV=22cm, and slice thickness=4mm. All experiments were conducted on a Bruker MedSpec 3T whole-body system (Ettlingen, Germany). The extraction of reference noise from the acquired images was described in (4). rPSD was defined as the respiratory or cardiac noise power over that of the entire spectrum obtained from each pixel's time course. Only pixels whose rPSDs exceed 0.08 were used for evaluation.

Results

The performance of NLMS adaptive filter under various levels of SNR is demonstrated in figure 2 and figure 3. rPSD improvements of the two subjects are shown in Table 1.

Discussions

From the simulation results, we show that NLMSADF can reduce nonstationary physiological noise to an acceptable level depending on the noise level. As expected, the proposed algorithm performs better under lower Gaussian white noise. In terms of physiological noise, it is interesting to note that the NLMSADF particularly works well under low SNR conditions. This is because as SNR gets higher, extraction of the reference signal becomes more difficult under nonstationary situations. In fact, it may not be necessary to use an adaptive filter when there exhibits sufficient SNR. We conclude that the efficacy of physiological noise suppression using NLMS adaptive filter is comparable with previous study (1) and is particularly suited for low SNR applications.

References

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4. Chuang et al. Proc. ESMRMB, 2000.

Fig. 1. NLMS adaptive filter structure

Fig. 2. NNPS at various levels of SNR2 obtained with 1000 repeated simulations. As Gaussian white noise decreases, lower NNPS can be obtained.

Fig. 3. NNPS at various levels of SNR1 obtained with 1000 repeated simulations. As SNR1 increases, it seems tracing the respiratory noise becomes more difficult.

rPSD(after filtering) rPSD(before filtering)	Subject1	Subject2
Cardiac	0.49±0.11	0.70±0.13
Respiratory	0.46±0.13	0.80±0.12