MEG Adaptive Noise Suppression using Fast LMS

Nayef E. Ahmar[1], Jonathan Z. Simon[1,2,3]
[1]Electrical and Computer Engineering, [2]Biology, [3]Bioengineering

Computational Sensorimotor Systems Lab

Introduction

Magnetoencephalography (MEG)

- Noninvasive,
- Temporal resolution ≤ 1 ms,
- Spatial resolution ~ 1 cm,
- Neural signals emitted ~ 10^{-13} T (Earth's magnetic field ~ $5x10^{-5}$ T),
- Shielding (reduces noise ~ 100 dB) necessary but not sufficient,
- Neural signal (plus noise) measured over 157 channels,
- External noise measured by 3 reference channels.

Adaptive algorithm and significance test

•Least Mean Square Method (LMS) computes filter coefficients that match noise in both reference and observed signals,
•Estimated noise in the observed neuronal signal is then subtracted,
•A fast version of LMS is adopted for speed [2],
•A joint Rayleigh-F-test compares significance of raw vs. filtered data[3],
•Fast-LMS vs. Continuously Adjusted Least-Squares method[1] (CALM).

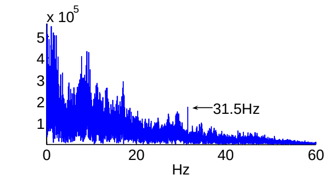


Fig.1 Periodogram of single channel response to a tone sinusoidally amplitude modulated at 31.5 Hz.

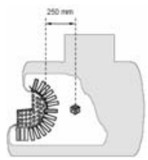


Fig.2 Three reference sensors in the horizontal dewar separated from the neuronal ones[1]

Methods

Stimuli and Data

•Sinusoidally amplitude-modulated sounds of 2 s long, 50 repetition each.
•20 stimuli at five modulation frequencies (1.5, 3.5 , 7.5, 15.5, and 31.5 Hz)
•Four different carriers (pure tone, 1/3 octave, 1 octave, and 5 octave pink noise all centered at 707 Hz).
•All stimuli were presented binaurally at approximately 70 dB SPL.
•Signals were recorded using a 160-channel, whole-head axial gradiometer system (KIT, Kanazawa, Japan)
•The magnetic signals were band-passed between 1 Hz and 200 Hz, notch filtered at 60 Hz, and sampled at the rate of 500 Hz.
•Responses to each stimulus from 300 to 2300 ms post-stimulus were concatenated, resulting in 20 responses (2 ms resolution, 100 s duration) for each channel.
•Each response was discrete Fourier Transformed (DFT), resulting in 20 complex frequency responses (0.01 Hz resolution, 250 Hz bandwidth) for each channel.

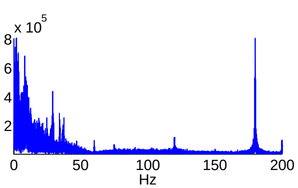


Fig.3a Periodogram of raw data.

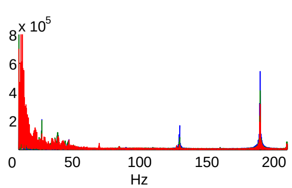


Fig.3b Periodograms for the 3 reference noise channels.

Fast LMS reduces noise without reducing signal

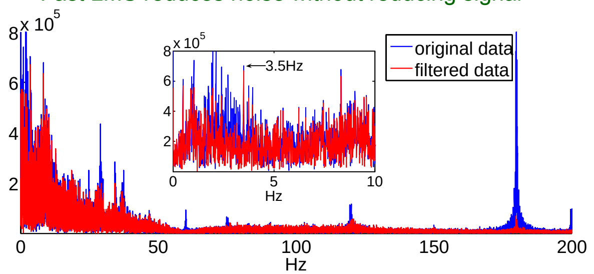


Fig.4 Periodogram of raw data (blue) vs. filtered data (red) of 1 channel using Fast LMS, (Block Size 128, adaptation constant 0.01). Magnified spectrum (0-10Hz) shows the response at the stimulus frequency (3.5Hz) with suppressed noise in the vicinity.

Adaptive filter model

•Neural and external noise are non-stationary.
•Adaptive process automatically adjusts the filter parameters to minimize estimation error.
• Normalized LMS method for the 3 reference channels (Fig. 5), where the adaptation of tap weight is based on error estimation is applied.
•Filter coefficients are those when convolved with the noise signal, capture the noise in the observed signal in a least mean square sense.
•With block LMS (Fast LMS), an improvement in execution time was achieved ~16 times faster than standard LMS with 1024 block size.

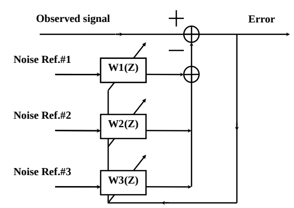


Fig.5. Three reference adaptive filter noise cancellation

Significance tests

•Performance of the adaptive noise suppression was evaluated by significance test [3].
•It is an equal contribution of F-test (amplitude info.) and Rayleigh test (phase info),
•Threshold was determined from average false positive rate iteratively and explicitly.

Results

Fast LMS increases number of significant channels

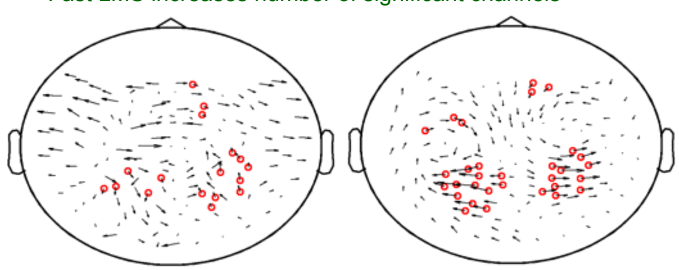
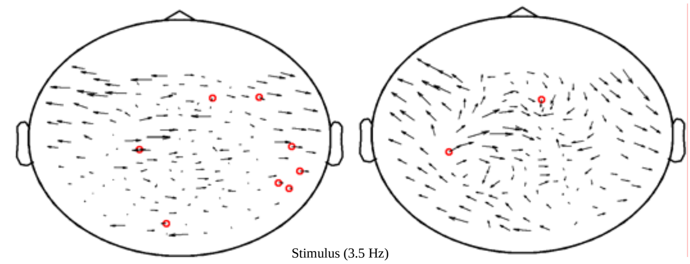


Fig.6a Raw data (3.5 Hz). Fig.6b Filtered data (3.5Hz).

•Arrows represent the magnetic field response, at each of 157 channels,
•Length of the arrow denotes amplitude,
•Orientation denotes phase,
•Circles mark those channels identified as significant by the joint balanced test ($p < 1/157$).

•Number of significant channels is boosted after filtering,
•Structure of the background of the head map is established,
•Most of the strong signals over the temporal lobes are de-noised.

Fast LMS reduces variability of false positives



Stimulus (3.5 Hz)
Response (15.5 Hz).

Fig.7a Raw data Fig.7b Filtered data

•On average, one false positive for all responses where no signal is expected.

•De-noising reduces Number of false positives,
•The variance of the false positives among different response frequencies per each stimulus frequency is always reduced.

Quantitative Measure

- Table 1 shows ratio of power between observed neural responses and noise responses captured by reference channels, for both raw and filtered data.
- Fast LMS preserved the signal at the stimulus frequency (3.5Hz).
- It removed 1.4 dB of noise for frequencies below 10Hz, ~19 dB around 180Hz, and 1.8 dB for the whole spectrum.

	Raw data	F-LMS Filter	CALM Filter
3.5Hz	11.8 db	11.5 db	10.0 db
1-10Hz	5.9 db	4.5 db	3.9 db
175-185Hz	6.3 db	-13.6 db	2.0 db
1-500Hz	6.7 db	4.9 db	4.9db

Table 1. Ratio of neural and noise power measurements for raw and filtered data.

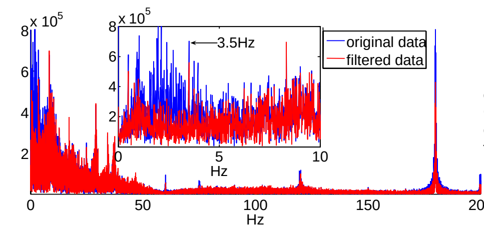


Fig.8 Periodogram of raw data (blue) and data filtered with CALM (red). One channel. Stimulus frequency is 3.5 Hz.

Fast LMS vs. CALM

- Continuously Adjusted Least Square Method (CALM), is a noise reduction procedure,
- It eliminates correlations between data and any of the 3 *unfiltered* reference magnetometers by removing the detected covariance from the data MEG sensors [1].
- This is performed, with a moving window of user-defined length.
- CALM removes more noise at lower frequency with the price of reducing the signal.
- It is less effective at high frequency and with narrow band noise.

Conclusion

Adaptive noise suppression is critical in noise suppression for MEG responses:
✓Improves SNR,
✓Increases number of significant neuronal channels,
✓Suppresses and regularizes false positives.
Although the algorithm exploits a block structure, the method is slower than other non adaptive filtering methods because of DFT computations.

References

[1] Adachi, Y., Shimogawara, M., Higuchi, M., Haruta, Y., & Ochiai, M. (2001). Reduction of nonperiodical environmental magnetic noise in MEG measurement by continuously adjusted least squares method. *IEEE Transactions on Applied Superconductivity*, 11, 669–672.
[2] S. S. Haykin, "Adaptive filter theory," Upper Saddle River, N.J., Prentice Hall (2002).
[3] N. Ahmar, Y. Wang, J.Z. Simon, "Significance tests for MEG response detection." Proceedings of the 2nd International IEEE EMBS Conference on Neural Engineering.