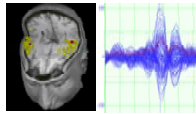


Introduction



Magnetoencephalography (MEG) is a noninvasive tool that measures the magnetic activity of the brain, using extremely sensitive devices such as Superconducting Quantum Interference Device (SQUID). MEG is a relatively new technique that promises good spatial resolution and extremely high temporal resolution (≤ 1 ms), thus complementing other brain activity measurement techniques such as Electroencephalography (EEG) and functional Magnetic Resonance Imaging (fMRI).

Because the magnetic signals emitted by the brain are on the order of a few femtoteslas (10^{-15} T,) shielding from external magnetic signals, including the Earth's magnetic field ($\sim 5 \times 10^{-5}$ T,) is necessary. Even with proper shielding, poor signal to noise ratio is a major challenge for Signal Processing research. We explore a de-noising method, identify its limitations in suppressing periodic noise, then we suggest a solution.

Motivation

Continuously Adjusted Least Square Method (CALM), used in the KIT-UMD MEG labs, reduces the non-periodical low frequency (< 10 Hz) noise during MEG measurements [1]. The noise reduction procedure essentially eliminates any correlation that the data MEG sensors have with any of the 3 reference magnetometers (25 cm apart from real data sensors) by removing the detected covariance from the data MEG sensors. This is performed data point by data point, with a moving window of certain length.

CALM algorithm is not designed to extract narrow band noise that could have a severe effect on data. Whence, some other complementary methods that precede applying CALM need to be addressed.

Experiment

Three sinusoidal amplitude-modulated tones at 32, 48, and 64 Hz, with a carrier frequency of 400 Hz were randomly presented for duration of 1 second per stimulus for a total of 300 epochs (100 per each stimulus). The MEG was recorded with 157 neuro-magnetometer channels sensitive to activities inside the brain as a response to the three stimuli. 3 additional reference magnetometer sensors recorded any magnetic activities coming from outside the brain.

Method

First, we look at the spectrum of raw data (Fig.1). As expected there are 3 peaks at 32, 48, and 64 Hz. However, they are barely noticeable due to noise. The spectrum of the noise is plotted in (Fig.2). We observe the narrow band noise at 17, 27, 36, and 60 Hz. Next we look at raw data processed through the CALM algorithm (Fig.3). The algorithm is designed to suppress only non periodic noise; however, in the presence of high amplitude narrow band noise, the moving window could be biased in the vicinity of such a noise (ex. 32 Hz peak in Fig.3.)

What we suggest instead, is removing the narrow band noise before applying CALM.

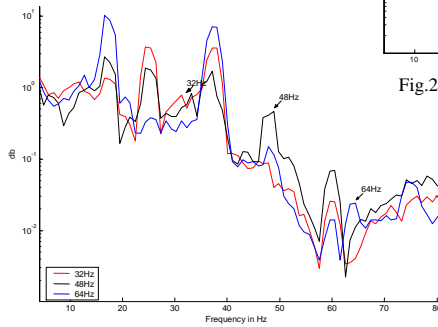


Fig.1 Spectrum of raw data

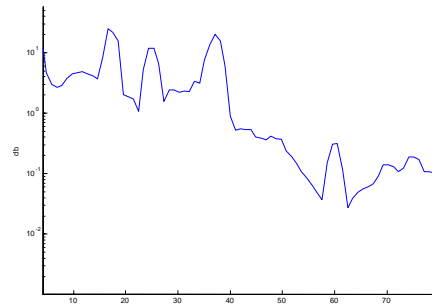


Fig.2 Spectrum of noise recorded by reference channels

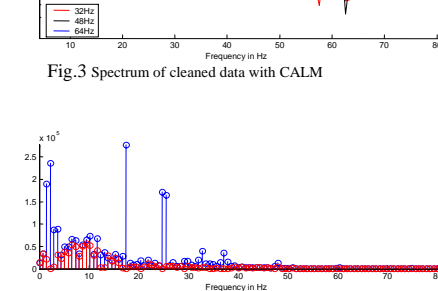


Fig.3 Spectrum of cleaned data with CALM

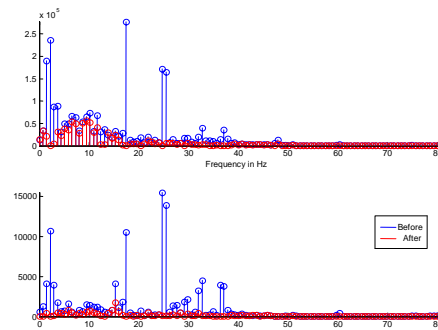


Fig.4 Top, Spectrum of neuronal channels before/after narrow band noise removal. Bottom, spectrum of reference channels before/after narrow band noise removal.

The method we use in suppressing such noise is described as follows:

- Remove corrupted presentations with artifacts (eye blink, swallowing, ...)
- Band pass filter [1-100 Hz], enough to cover Delta to Gamma bands,
- Decimate and remove DC component,
- Window: divide the spectrum into smaller windows to capture the $1/f$ shape of neuronal signals,
- Zero pad: interpolate for a better capture of noise frequency index
- FFT and threshold estimation,
- Detect and correlate high peaks in reference and neuronal channels,
- Phase and amplitude computation, sinusoid recovery.

We keep running the algorithm for every epoch, until there will be no narrow band noise within the constraint we impose. Fig.4 shows the effect of the algorithm on neuronal data (top) and on reference channels (bottom).

Results and Discussion

After removing noise, we average the steady state response of the signal for each stimulus over all presentations. Using Multitaper method [2], we look at the spectrum. Fig.5 shows a better capture of the anticipated peaks as compared with CALM. We enhance these results simply by dividing by the spectrum of the brain signals for the same epoch with the absence of any stimulus (Fig.6).

An improvement in Signal to Noise Ratio of 13db on average was observed (Fig.7). The algorithm detected and successfully suppressed the high narrow band peaks present in both the reference and neuronal channels. Only the 48 Hz peak was originally evident in the case of Raw/CALM data analysis, mainly because of the good response of brain activity at that frequency. By removing narrow band noise, we were able to recover peaks at 32 and 64 Hz.

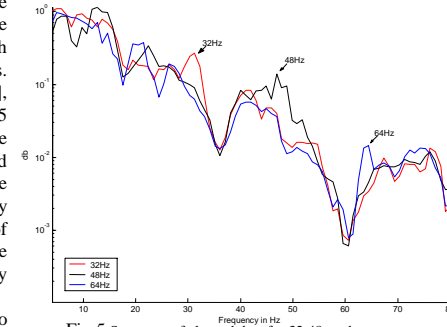


Fig.5 Spectrum of cleaned data for 32,48, and 64 Hz stimulus AM modulated signals

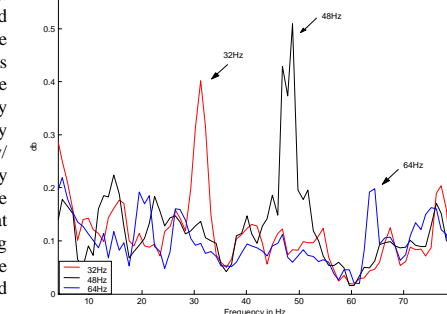


Fig.6 Spectrum for 32,48, and 64 Hz stimulus AM modulated signals divided by non stimulus signals

Conclusion and Future Work

In this work, we show how important it is to suppress narrow band noise before applying such algorithms as CALM, then we present a method that recover peaks buried in noise that could not be recovered otherwise.

More work is sought to further validate the non invasiveness of the algorithm to the neuronal data, test the algorithm with more complex stimuli, optimize the code and automate the setting of the thresholds, to be followed by integrating the method with CALM.

References

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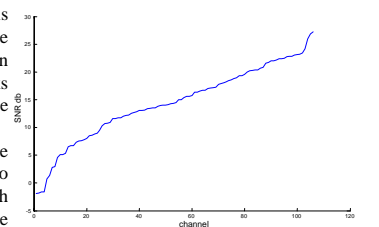


Fig.7 SNR difference before and after applying narrow band de-noising, for each channel