PREDICTIVE MATCHING PURSUIT

An Improved Signal Representation and Feature Extraction Method with Applications to Neural Signals

Penn UNIVERSITY of PENNSYLVANIA

Weixuan Chen[1], Brian Litt[1,2], Gershon Buchsbaum[1]

[1]Department of Bioengineering, University of Pennsylvania

[2]Department of Neurology, School of Medicine, University of Pennsylvania

Introduction

Matching pursuit is an effective method of signal representation and feature extraction widely used in neural signal analysis. However, its traditional implementation is slow and computationally demanding, restricting its use in real time practical applications, especially when the analyzed data has numerous channels such as in electroencephalography (EEG). We propose a new faster matching pursuit algorithm, *predictive matching pursuit*, and verify its speed improvement in neural signal applications.

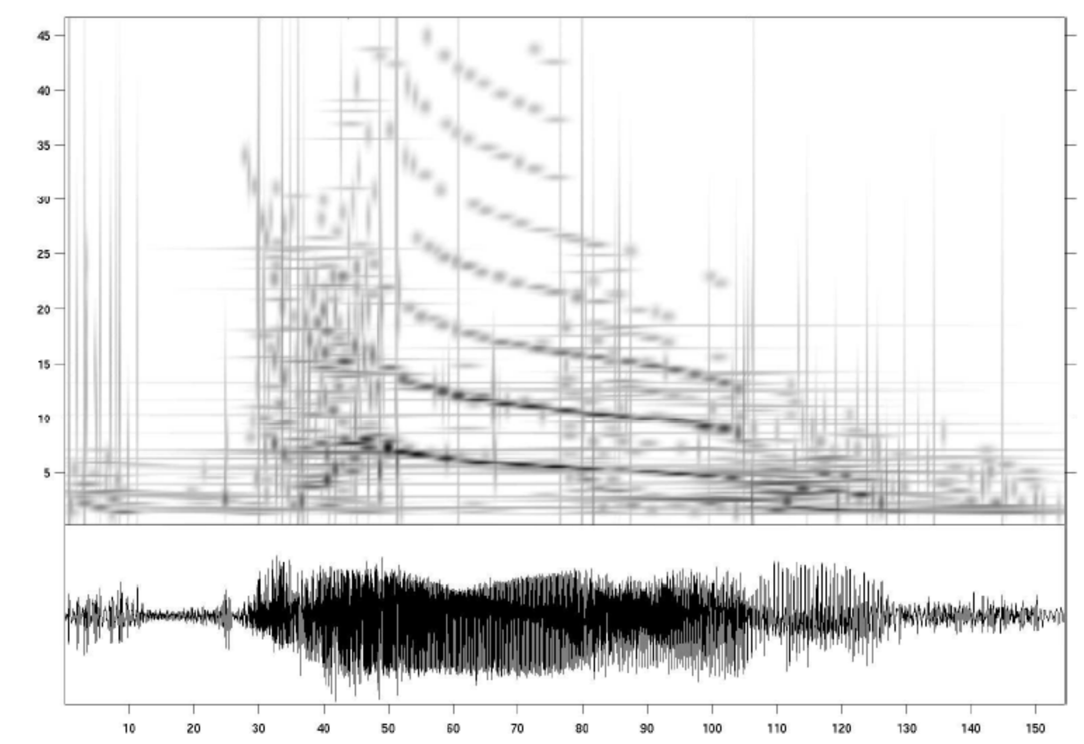
Matching Pursuit

Matching pursuit (MP) is an algorithm that decomposes a signal into a linear expansion of waveforms that are selected from a redundant dictionary of functions. From this large dictionary of possible functions, a sub-family of time-frequency atoms is chosen in such a way as to best match the local signal structures. The family of time-frequency atoms is created by scaling, translating, and modulating a window function g(t):

$$g_\gamma(t) = \frac{1}{\sqrt{s}} g\left(\frac{t-u}{s}\right) e^{i\xi t}$$

where s > 0 is scale, ξ is frequency modulation, and u is translation [1].
The minimum of time-bandwidth product is obtained when g(t) is Gaussian. In this case, g_γ are called Gabor functions (Gauss modulated by sinus).

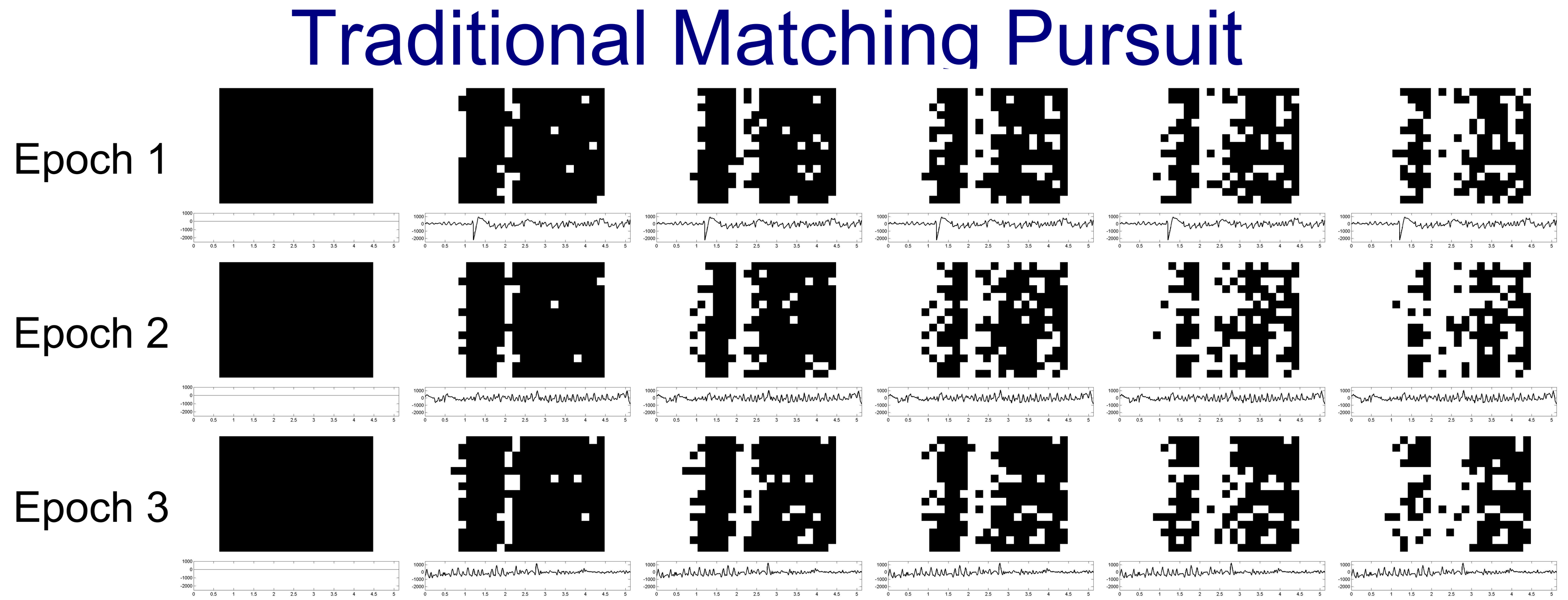
Applications to Neural Signals



The waveforms selected by matching pursuit are adaptively matched to the local signal patterns. This kind of analysis is especially suitable for characterizing transients appearing randomly in the signal, such as sleep spindles, K-complexes, epileptic spikes and high frequency oscillations (HFOs). For example, the time-frequency map of an epileptic signal can be drawn with a better resolution than the Fourier Transform and the wavelet transform. In addition, the parameters extracted by matching pursuit can be also used to do seizure detection and foci localization.
The figure above is the two-dimensional representation of energy density of matching pursuit atoms in an intracranial recording with a seizure [2]. Horizontal axis-time [s], vertical (on the time-frequency plot) [Hz].

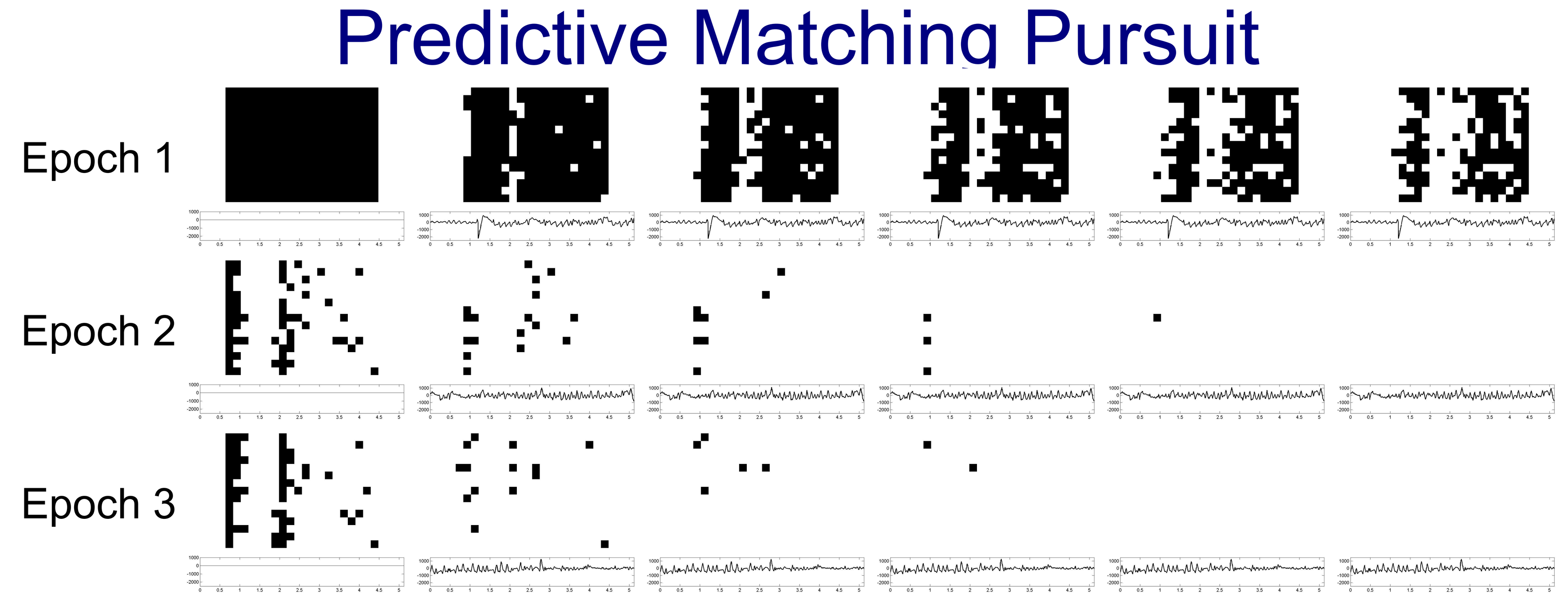
Methods

Traditional Matching Pursuit



The traditional matching pursuit algorithms are restricted within every epoch, and never utilize information collected from the previous epochs. The figures above illustrate the decomposition process of three successive epochs within an electrocorticographic (ECoG) signal using traditional matching pursuit. In each frame, the figure below shows the reconstructed signal, and the figure above shows the atoms already selected by matching pursuit. (Every black pixel represents an atom in the dictionary. When it is selected, it turns white.) As can be seen, traditional matching pursuit searches among the entire dictionary regardless of how many epochs it has processed. This is inefficient and what we will improve.

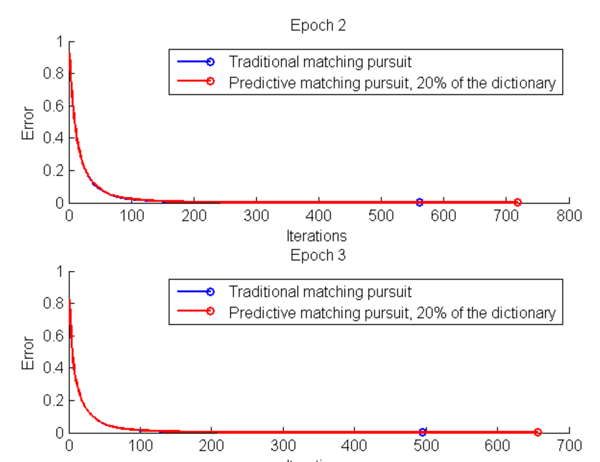
Predictive Matching Pursuit



Since the signal feature variability over epochs is limited, a majority of Gabor dictionary atoms have a very low probability of appearing in the representation. Therefore, as we get more and more information about the signal structure during matching pursuit, we can reduce the size of the Gabor dictionary according to some criterion.
The figures above illustrate the decomposition process of the same three epochs using predictive matching pursuit. Even though search among the whole dictionary is still required for the first epoch, the dictionary sizes for the second and third epochs are greatly reduced based on the prediction of their signal structures. As a result, the decomposition of the same signal can be done with a much higher speed and nearly no precision loss.

Performance

(a)



(b)

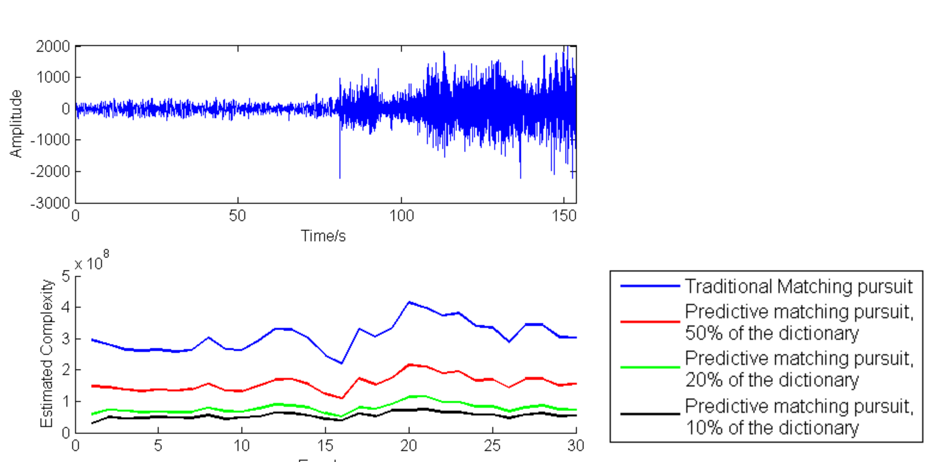


Figure (a) compares the performance of *predictive matching pursuit* with traditional matching pursuit. For the two epochs examined, the error curves of both methods share the same trend before reaching a reconstruction accuracy of 99.99%. However, *predictive matching pursuit* uses only 20% of the original dictionary for the same error rate. Figure (b) shows the time course of an ECoG signal with a seizure (top) and the estimated time complexity (a measure of the computational load to perform the signal decomposition) corresponding to each 5-second epoch of it using different implementation algorithms (bottom).

Future Work

- Evaluate the algorithmic performance more precisely using the Performance Application Programming Interface (PAPI)
- Explore the effect of the correlations among epochs on the performance of predictive matching pursuit
- Implement real-time detection of epileptic seizures in ECoG signals using predictive matching pursuit

[1] Durka, P. J., & Blinowska, K. J. (1995). Analysis of EEG transients by means of matching pursuit. Ann Biomed Eng, 23(5), 608–611.

[2] Franaszczuk, P. J., Bergey, G. K., Durka, P. J., & Eisenberg, H. M. (1998). Time-frequency analysis using the matching pursuit algorithm applied to seizures originating from the mesial temporal lobe. Electroencephalogr Clin Neurophysiol, 106(6), 513–521.