USING SINGLE/MULTI-CHANNEL ENERGY TRANSFORM AS PREPROCESSING TOOL FOR MAGNETOENCEPHALOGRAPHIC DATA-BASED APPLICATIONS

D. Gutiérrez, Member, IEEE

Centro de Investigación y de Estudios Avanzados (CINVESTAV), Unidad Monterrey, Apodaca, N. L., 66600, México
Email: dgtz@ieee.org

ABSTRACT
The purpose of this preliminary work is to evaluate the effectiveness of the single/multi-channel energy transform (ET) as preprocessing tool for magnetoencephalographic (MEG) data-based applications. The ET is a derivative-based transformation that enhances either the variability content of a signal from a single channel, or the compound variability content of signals from multiple channels. In the case of the single-channel ET, a spatial focusing effect in MEG data is achieved, which is a desirable effect given that MEG spatial variability can be correlated to regions of brain activity. On the other hand, when the ET is applied to channels that have been grouped following certain anatomical or physiological criteria, the variability content of the group gets concentrated and a signal compression is achieved. This effect can be useful in MEG-based brain-computer interfaces (BCI) where channel density compression is desired when going from training data to real life applications. Both the spatial focusing and compression properties of the ET are demonstrated with real MEG experiments.

Index Terms— energy transform, array processing, magnetoencephalography

1. INTRODUCTION
Magnetoencephalography (MEG) is commonly used for quantitative assessment of brain activity, especially for source localization [1]. The overall goals of MEG analysis are twofold: first, enhancement of signal-to-noise ratio (SNR) of electrophysiological signals so that they may be readily identified and classified; second, determination of where the signals originate [2].

Historically, MEG data analysis has focused on the ubiquitous averaged evoked response paradigm, where the activation of some areas of the brain are assumed to be time-locked to external events, either to a stimulus or to a motor outflow [3]. Then, averaging the MEG data over a number of independent responses improves the SNR of the time-locked fraction of the brain activity. However, signal averaging does not make use of the spatial and temporal correlation that MEG signals exhibit. Such information could be useful to study brain regions with variable latencies, e.g., those serving higher cognitive functions from which averaged signals cannot faithfully reproduce the character of their sources.

This paper evaluates the use of the energy transform (ET) as a preprocessing tool that takes into consideration the spatial correlations between signals from different measuring channels while enhancing the variability information of the signals individually or in groups. The ET has been previously used in the detection of QRS complexes in electrocardiographic (ECG) data [4]. Given its superior performance for feature extraction in comparison to conventional transforms, the ET has been also used in brain-computer interface (BCI) applications as a preprocessing tool to enhance electroencephalographic (EEG) data [5].

As a proof of the concept, the potential applications of the ET to MEG data-based typical applications are explored here. However, the use of the ET can be easily generalized to different array processing problems. In Section 2, the ET is formally introduced in both its single- and multi-channel versions. Section 3 shows the potential applications of the ET through numerical examples using real MEG data. Finally, the results and future work are discussed in Section 4.

2. METHODS
Consider the case of an MEG array with \( M \) measuring channels. Then, define \( y_{m}(n) \) as the \( n \)th measurement, where \( n = 1, 2, \ldots, N \) time samples and \( m = 1, 2, \ldots, M \). Under the previous conditions, the multi-channel ET is given by

\[
e_j(n) = \sum_{\tau=n}^{n+q-1} \sum_{k=1}^{K_j} (y_{s_{j,k}}(\tau) - y_{s_{j,k}}(\tau - 1))^2, \quad (1)
\]

where \( q \) is the length of the processing window, and \( j = 1, 2, \ldots, J \) is the index of the set of channels \( S_j = \{s_{j,k} \mid s_{j,k} \in m, \text{ for } k = 1, 2, \ldots, K_j \} \) over which the transformation is performed. Those sets of channels are formed by grouping the \( M \) channels in \( J \) sets where each channel belongs only to one set but each set can contain a
different number of channels $K_j$. The criterion to group together different channels will depend on the application, as it will be seen in the following sections.

For the case when no grouping is performed at all and there are $J = M$ sets each containing an individual channel, i.e. $K_j = 1$ and $j = m$, the transformation defined by (1) reduces to

$$e_m(n) = \sum_{\tau=n}^{n+q-1} (y_m(\tau) - y_m(\tau-1))^2,$$

which corresponds to the single-channel ET.

The ET can be interpreted as a short-term energy estimate of the signal or group of signals and it can be explained as a linear digital filter (derivative algorithm and moving window integrator) followed by a non-linear transformation (signal amplitude squaring) [6]. While the derivative enhances the variability content of the signal, the squaring process intensifies the frequency response curve of the derivative. Depending on the value of $q$, the moving window integrator produces a signal that includes information about both the slope and the width of the original signal. Previous results show that large values of $q$ are useful in detection problems [6], while low values are preferred for signals with variable latencies, such as those in EEG/MEG data-based studies (see e.g., [5]).

3. EXPERIMENTS

In this section, the potential applications of the single/multi-channel ET are shown through a series of experiments on real MEG data.

3.1. Measurements

MEG measurements were obtained using a CTF 275-channel system [7]. The data correspond to contra-lateral brain activation after stimulation to the median nerve was applied in either the left or right wrist of a healthy patient with a vibrating piezo stimulator. 300 independent measurements of the activation at each side of the brain were obtained at a sampling rate of 600 Hz. Then, the data was band-pass filtered in the range of (5, 40) Hz with a 5th order Butterworth filter.

3.2. Single-channel energy transform

The single-channel ET has been previously used in ECG data processing in order to enhance the high variability components of the signal, specifically the QRS complex which is associated to heart’s ventricular depolarization, while suppressing other complexes as well as noise and artifacts. For that purpose, the ET has proven to be effective even in cases of small QRS complexes [8].

A first approach to use the ET to process data from brain activity is described in [5], where the authors report a significant improvement in the correct classification ratio of an EEG data-based BCI when the data were transformed with the single-channel ET while using a sufficiently large number of independent trials at training stage. Further improvement in BCI systems could be achieved by using MEG data since brain signals exploited by EEG and MEG are fundamentally the same. However, MEG has the advantage of being easier to interpret and suffers far less spatial blurring due to the isolating effect of the layers of the head. Therefore, some research groups are exploring the use of MEG data in BCI applications hoping that the improved MEG signal properties translate into increased BCI communication speed [9].

In that sense, the ET becomes useful as a preprocessing tool to enhance MEG signals, even for the case when few independent trials are available. This is shown in Figures 1 and 2, where the single-channel ET was applied to the MEG data described in Section 3.1 after averaging over 5 or 50 independent trials. In the case of Figure 1, the ET improves the focalization of the source of brain activity even after a high SNR has been achieved by averaging over 50 independent trials. Still, Figure 2 shows the spatial focalization effect produced by the ET for the case of a low SNR (corresponding to the case of averaging only over 5 trials). These results have two implications: first, the ET is capable of focalizing the source even for low SNR, which is useful in source localization analysis; second, the number of required trials could be reduced, which translates to a faster training process in BCI applications.

3.3. Multi-channel energy transform

Many technological restrictions are against using MEG data in BCI applications: the expensive technology associated to it, its immobility, and its vulnerability to magnetic noise are some of them. However, MEG-based BCI systems seem possible as technology progresses to the point of having portable MEG devices. Meanwhile, users could benefit from working on a MEG-based BCI in the training stage, and then move to a more portable EEG-based system in a real-life scenario. In order to do that, a method must be provided to compress, without losing relevant information, the signals acquired with a high spatial density technique as MEG, and then correlate it to measurements obtained through EEG, which has a much lower spatial density as well as less signal focalization.

The ET could provide a solution to such problem of lossless MEG data compression by means of (1) if the density reduction is done using an anatomical criterion. For example, Figure 3 shows the result of applying the multi-channel ET to the MEG signals after being averaged over 50 trials. In this case, the MEG measuring channels were grouped together according to $J = 14$ anatomical regions described next (a two-letter nomenclature and number of channels $K_j$ for the anatomical regions are shown in parenthesis): central-frontal (ZF-3), central-central (ZC-4), central-parietal (ZP-1), central-occipital (ZO-3), left-frontal (LF-33), left-central-frontal (ZF-3), central-occipital (ZO-3), left-frontal (LF-33), left-
Fig. 1. Brain activation averaged over 50 trials showed through MEG data (a and b) and the corresponding ET (c and d).

Fig. 2. Brain activation averaged over 5 trials showed through MEG data (a and b) and the corresponding ET (c and d).
central (LC-24), left-parietal (LP-22), left-occipital (LO-19), left-temporal (LT-34), right-frontal (RF-33), right-central (RC-24), right-parietal (RP-22), right-occipital (RO-19), and right-temporal (RT-34). The anatomical regions and the corresponding channels were provided by the manufacturer of the MEG system [7].

As a result of applying the ET to the previously described configuration, an energy map that clearly shows the contra-lateral distribution of the brain activity is obtained. Since the LT and RT groups have more channels than other groups and the brain activation is stronger in those regions, the energy maps shown in Figure 3 are biased towards the temporal region. For an unbiased comparison, it is necessary to have the same number of channels in each group. However, a biased result could be useful in certain applications where discrimination of contra-lateral activity is desired, such as in BCI. In that sense, the results in Figure 3 show that discrimination between left or right stimulation is possible by means of the proposed multi-channel ET. Furthermore, the ET is capable of providing the means to obtain high rates of correct discrimination even when few independent trials are averaged (i.e., low SNR). This is shown in Figure 4, where the MEG signals were averaged over only 5 trials but the energy maps still can be discriminated as being produced by a left or right stimulation.

4. CONCLUSIONS

This paper presented the potential applications of the ET as a preprocessing tool for MEG data-based applications. In its single-channel version, the ET can improve source focalization even for low SNR data. Given its easy implementation, the single-channel ET has the potential of improving MEG source localization techniques in terms of accuracy (given by the better focalization of the source) and processing time (as less independent trials are required).

The multi-channel ET could be useful in the process of going from the training phase on an MEG-based BCI to a real-life BCI system based on EEG. In that scenario, the ET is helpful in the process of discriminating brain activity of different events, assigning a group of measuring channels to each event, and compressing the data from each group into an energy signal that keeps the compound variability information of the event. Furthermore, the process of grouping MEG channels based on anatomical and physiological criteria can be useful in determining the optimal position of the EEG channels in real-life BCI implementations.

Further work in this area will include applying the ET in multi-class BCI systems based on MEG data related to motor and cognitive brain processes. A performance analysis of using the ET in combination with different brain source localization methods based on EEG/MEG data will also be part of the future work.

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6. REFERENCES


Fig. 4. Energy transform of brain activation averaged over 5 trials. In this case, MEG channels were grouped in 14 anatomical regions, whose centroid’s location is denoted by dots over the head.