



EEGLAB – A suitable toolbox for casual BCI research

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ABSTRACT: EEGLAB is a MATLAB based open source toolbox which is widely used for analysis of continuous and event related electrophysiological data. In this work EEGLAB is utilized for the purpose of event related data analysis in a casual BCI research. This tool box is equipped with capabilities like importing data of various formats; pre-processing data accumulated using various techniques of filtering, re-sampling, averaging, etc.; Visualization and Classification of the data using various techniques. Moreover the extensible plug-in architecture enables users to add extra functionality such as source localization, connectivity estimation and designing of casual brain-computer interfaces.

Keywords: EEG analysis, MATLAB, BCI, Open source toolbox.

I. INTRODUCTION

Brain computer interface (BCI) research is the outcome of J.Vidal's concept of direct communication between brain and computer in early 1973 [1]. It was having the main application in the medical field but in recent past its non medical uses have gained momentum and will be the focus of this work [2]. A casual BCI (Non Medical BCI) consists of basic building blocks like data acquisition, pre-processing, feature extraction, classification and feedback segments along with the software toolbox binding all the segments together.

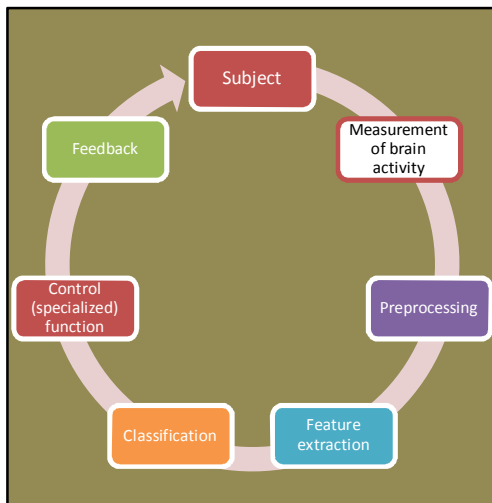


Fig. 1. General block diagram of a BCI.

Several research groups have their own closed source software tools, unavailable (available commercially) to public as they are used for in-house testing and in-house BCI developments only. On the contrary, I am using EEGLAB, which is a MATLAB based toolbox for EEG signal processing and analysis developed by Swartz Center for Computational Neuroscience (SCCN), a center of the Institute for Neural Computation, The University of California San Diego (UCSD) [3]. This software toolbox was made open source in the year 1997 by S Makeig, however it was not successfully experimented for Casual BCI until recently.

II. BASIC FUNCTIONALITY

Pre-processing of data: EEGLAB can import files from different data formats like MATLAB, BCI2000, ASCII, Neuroscan, Biosemi, BrainVision, etc [4]. This makes it compatible with most of the data acquisition devices based on various software platforms. Moreover, standard pre-processing methods available in EEGLAB, which includes FIR and IIR filters, epoch extraction, baseline removal, re-sampling and re-referencing makes this toolbox very handy. Additionally, data channels can be obliterated or interpolated and artifacts can be removed using fully or partially automated methods based on channels or epochs.

Events and data structure: This toolbox uses only one structure for storing data, acquisition of parameters, epoch information, events and channel locations in a EEGLAB dataset.

This structure is easily accessible from MATLAB command line. This allows users to edit, review and transform the epoch and event information. This toolbox has functions to compute and visualize epoch and event statistics also [5].

III. VISUALIZATION OF DATA

It is done through a scrollable and interactive view which displays specific number of channels in a specific time range [6]. Fig 2 shows this channel activities window with event markers and a custom selection. This is particularly useful for manual artifact rejection, where one could select signal segments with the help of a mouse.

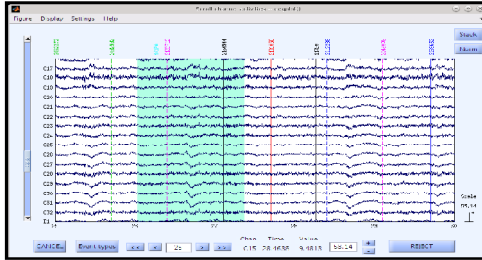


Fig. 2. Signal browser.

IV. INDEPENDENT COMPONENT ANALYSIS (ICA)

It is an important fact that mostly all activities recorded from scalp electrodes are the volume conducted sum of activities originating within a number of cortical domains. This toolbox uses independent component analysis (ICA) to detach these activities under the assumption that their activities are temporally independent. The algorithms used to detect and isolate artifacts like eye movements and electrocardiographic signals are based on ICA [7,8]. Furthermore, it can separate biologically plausible dipolar brain sources also.

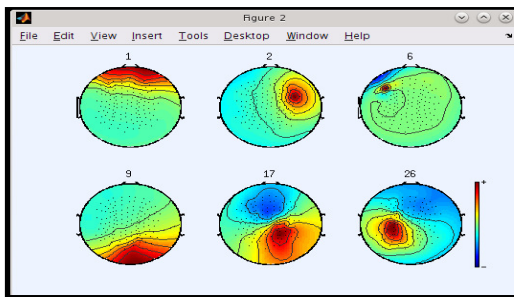


Fig. 3. Scalp maps for six independent components.

V. TIME/FREQUENCY ANALYSIS

The principal measures are the baseline or epoch mean power spectrum and the following event related time/frequency measures:

(1). Event-related spectral perturbation (ERSP) which measures mean event-related changes in the power spectrum at a data channel or component. Calculating it requires computation of the power spectrum over a sliding latency window and then averaging across data trials. The colour at each image pixel then indicates the power (in dB) at a given frequency and latency relative to the time locking event [9]. Typically, for n trials, if $F_k(f, t)$ is the spectral estimate of trial k at frequency f and time t

$$ERSP(f, t) = 1/n \sum_{k=1}^n |F_k(f, t)|^2$$

To compute $F(f, t)$ EEGLAB uses either the sinusoidal wavelet transform, short time Fourier transform or a Slepian multi-taper decomposition that provides a specified time and frequency resolution [10].

(2). Inter-trial coherence (ITC) gives magnitude and phase at a single channel or component [11]. The term 'inter-trial coherence' refers to its interpretation as the event-related phase coherence (ITPC) or event-related linear coherence (ITLC) between recorded EEG activity and an event-phase indicator function. Inter-trial phase coherence is defined by:

$$ITPC(f, t) = 1/n \sum_{k=1}^n \frac{F_k(f, t)}{|F_k(f, t)|}$$

and Inter-trial linear coherence by

$$ITLC(f, t) = \frac{\sum_{i=1}^n F_k(f, t)}{\sqrt{n \sum_{k=1}^n |F_k(f, t)|^2}}$$

(3). Event-related cross-coherence (ERCOH) gives the magnitude and phase between two data channels or components activities in a sets of trials to determine the degree of synchronization between the two activity measures [12]. In EEGLAB, for two signals, a and b , Phase cross-coherence is defined by

$$ERPCOH^{a,b}(f, t) = 1/n \sum_{k=1}^n \frac{F_k^a(f, t) F_k^b(f, t)^*}{|F_k^a(f, t) F_k^b(f, t)|}$$

And linear cross-coherence by

ERLCOH^{a,b}(f, t)

$$= \frac{\sum_{i=1}^n F_k^a(f, t) F_k^b(f, t)^*}{\sqrt{\sum_{k=1}^n |F_k^a(f, t)|^2} \sqrt{\sum_{k=1}^n |F_k^b(f, t)|^2}}$$

VI. USER INTERFACE

The graphic user interface (GUI) of this toolbox allows non-experienced MATLAB users to apply advanced signal processing techniques to acquired data. On the other hand more experienced users can use the GUI to save time in writing custom and/or batch analysis scripts by incorporating menu shortcuts and history functions. Table I provides example scripts of different levels of complexity

Table 1: EEGLAB processing scripts.

```
.1. >> pop_erpimage(EEG);

2. >> figure; pop_erpimage(EEG, 1, [1], [],
'Channel 1
erpimage', 10, 1);

3. >> erpimage(EEG.data(1,:), ones(1, EEG.trials
) *
EEG.xmax * 1000, linspace( EEG.xmin * 1000,
EEG.xmax * 1000, EEG.pnts), 'Channel 1 ERP
image', 10, 1, 'topo', {1 EEG.chanlocs }, 'erp',
'cbar');
```

EEGLAB functions may be roughly divided into three layers designed to increase ease-of-use for different types of users:

- 1. GUI-based use:** Inexperienced MATLAB users can choose to interact only with the main EEGLAB window menu, first to import data into EEGLAB and then to call any of a large number of available data processing and visualization functions by selecting main-window menu items organized under various headings.
- 2. EEGLAB command history:** Middle level users may first use the menu to perform a series of data loading, processing and visualization functions and then may take advantage of the EEGLAB command history functions to easily produce batch scripts for processing similar data sets.
- 3. Custom EEGLAB scripting:** More experienced MATLAB users take advantage of EEGLAB functions and dataset structures to perform computations directly on datasets using their own scripts that call EEGLAB and any other MATLAB functions while referencing EEGLAB data structures.

VII. DISTRIBUTION, DOCUMENTATION AND SUPPORT

EEGLAB is distributed under the GNU (General Public License). The complete source code is publicly available. It is based on the commercial MATLAB software environment. Most of the functions also run under Octave, an open source software environment compatible with MATLAB. However, graphical output is not fully functional. The documentation part is freely available on the web, featuring hands-on tutorials, online workshops, wiki, frequently asked questions (FAQ), bug report interface, mailing lists for news and discussions along with a support email account.

VIII. RESULT AND DISCUSSION

There is no clear boundary between data analysis for BCI and for neuroscience in EEGLAB. The casual BCI system designed here has EMOTIVE kit working as acquisition system which maps continuous EEG data from casual users connected through Lab Streaming Layer (LSL). Moreover EEGLAB also provides a large collection of components that could be used to construct BCI detectors. This toolbox also aids in implementing custom signal processors and machine learning algorithms by the user. Here in this work EEGLAB is used as a complete interactive environment for processing EEG data in MATLAB. It has successfully provided both standard and advanced EEG processing functions significant for casual BCI. EEGLAB is also having a strong orientation towards ICA and event related time/frequency analysis. The software toolbox provides transparent data processing as possible and allows users to tune their parameters easily. Moreover the functionality of EEGLAB can be extended with plugins. Currently, around 35 EEGLAB plug-ins, 10 of which are included in the core EEGLAB distribution. Future development of EEGLAB is possible and should focus on supporting, maintaining and integrating important plug-ins specified for Casual BCIs.

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