On the development of a simple EOG-based mouse with BCI technology applying Empirical Mode Decomposition and DWT

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Abstract

This paper presents an on-going project on the development of a simple cursor control emulating the typical operations of a computer-mouse, using Electrooculography signals (EOG) obtained indirectly through a commercial 16-electrodes wireless headset originally used to acquired EEG signals. The cursor position is controlled using information from a gyroscope included in the headset. The clicks are generated through the user's blinking with an adequate detection procedure based on spectral analysis. Empirical Mode Decomposition (EMD) technique is explored as a simple and quick computational tool, yet effective, aimed to the pulse detection in a noisy signal, as well as a validation method to distinguish between natural blinking and blinks for control. EMD is compared with a spectral analysis based on the Discrete Wavelet Transform (DWT). The experimental setup, some obtained results, and a comparison among the two used spectral analysis, are presented.

Introduction

The expression "Brain Computer Interface" (BCI) has been used to describe generically, systems which allow people to control computer applications using their brain signals. In recent years, there has been a growing interest in the research community on signal processing techniques oriented to solve the multiple challenges involved in BCI applications [1, 2]. An important motivation to develop BCI systems, among some others, is to allow an individual with severe motor disabilities to have control over specialized devices such as assistive appliances, neural prostheses, speech synthesizers, or a personal computer directly. The standard computer interface nowdays involves a keyboard and mouse, although recently, touchscreen interfaces are becoming very popular. Computer mouse emulation using hands-free alternatives has been a growing research area in recent years. The following is a partial list of some successful modalities which have been reported: visual tracking [3], voice control [4], electromyographic signals [5], electro-oculographic potential (EOG) [6], and electroencephalographic signals [7, 8]. In this work we present an on-going project focusing on the development of a hands-free mouse emulation using the EEG headset recently released by Emotiv Co. Cursor position is controlled through the speed signals obtained from a gyroscope included in the headset. The clicks are carried out through the user´s blinking, detected from the EOG signal which is indirectly read through the headset electrodes. For that purpose, Empirical Mode Decomposition (EMD) is explored as a separation technique in order to locate in time and frequency, the energy of the associated pulses from a background with noise and other artifacts. EMD is a technique used to decompose a time series into a finite number of functions called intrinsic mode functions (IMF) using an empirical identification based on its characteristic time scales. EMD has been recently proposed as an analysis tool in a number of applications such as, image texture analysis [9], detection of human cataract in ultrasound signals [10], crackle sounds analysis [11], vibration signal analysis for localized gearbox fault diagnosis [12], image watermarking [13], and EEG signal analysis. Examples of the last category, closely related to the topic of the presented paper are event related potentials (ERP) [14], phase synchrony measurement from the complex motor imaginary potential of combined body and limb action [15], and EEG signals for synchronization analysis [16].

Empirical Mode Decomposition (EMD)

EMD was first introduced by Huang [17] for spectral analysis of non-linear and non-stationary time series, as the first step of a two stage process, currently known as the Hilbert Huang Transform (HHT). Essentially, EMD aims to empirically identify the intrinsic oscillatory modes or intrinsic mode functions (IMF) of a signal by its characteristic time scales, in adaptive way. These modes represent the data by means of local zero mean oscillating waves obtained by a sifting process. EMD can be summarized as follows (see ref. 18 for details): Given a signal $x(t)$ identify its extrema (both minima and maxima). Generate the envelope by connecting maxima and minima points with a cubic spline (interpolation). Determine the mean by averaging $m(t) = (e_{min}(t)+e_{max}(t))/2$. Extract the detail $d(t) = x(t) - m(t)$. Iterate on the residual $m(t)$. Figure 4 shows typical results obtained from an EEG signal using EMD with four decomposition levels.

Discrete Wavelet Transform (DWT)

DWT is a well known transformation used to analyze the time-scale energy distribution of non-stationary signals [19]. Briefly, DWT is defined by the equation $W(j,k) = \sum_j \sum_k f(x) 2^{-j/2} \psi(2^{-j}x - k)$, where the set of functions $\psi_{j,k}(n)$ is referred to as the family of wavelets derived from $\psi(n)$, which is a time function with finite energy and fast decay called the mother wavelet. The DWT technique used in this work is the so called sub-band coding algorithm, which is implemented in terms of filter banks by successive high-pass and low-pass filtering of the time signal and down-sampling by two. The number of wavelet decomposition levels is defined by the user depending on the desired level of scale resolution, and the number of available samples in the time domain. Five decomposition levels, determined by experimentation, are used in this work.

Experimental setup and results for double-blinking signal detection and gyroscope data processing

Subjects under testing were seated in a comfortable position using the Emotiv headset with a laser pointer attached at the top, as shown in figure 1. A simple application developed in visual basic, shows a red circle moving through the screen following horizontal and vertical displacements, with a linearly increasing speed. The subject is instructed to follow as closely as possible the red circle with the pointer. EEG and gyroscope data are recorded simultaneously. Additionally, the subject was told to do a double blinking when a black circle appears in the screen. In that instant, the application sends a marker to the recording system. Testing setup system is depicted in figure 2.

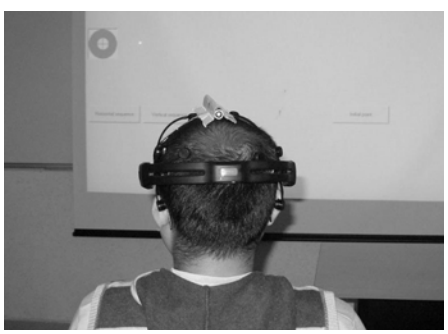

Figure 1. Experimental setup of EEG-based mouse emulation.

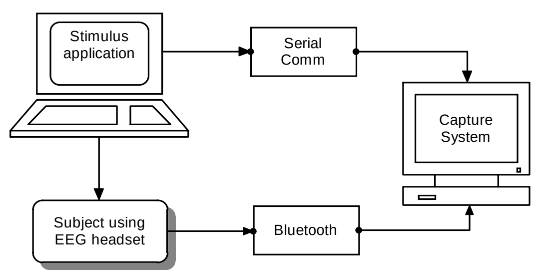

Figure 2. Testing setup system.

The modules proposed to detect double-blinking event and to process gyroscope data are shown in the block diagram of figure 3. The EEG signal required to perform the detection is obtained from electrodes AF3 or AF4, labeled according to the 10-20 international system. A preprocessing stage using a band-pass filter (0.5Hz - 10Hz) is applied before doing the spectral analysis.

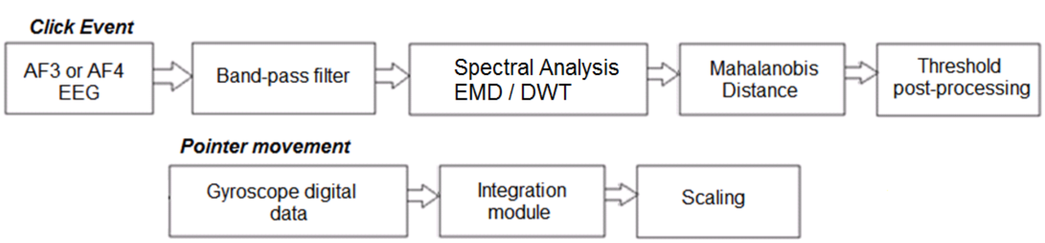

Figure 3. Blinking detection and gyroscope processing system.

Gyroscope IC embedded in Emotiv headset provides information about head movements in the form of a speed signal. An integration step is then required in order to obtain the cursor relative position. Figure 4-a shows a typical gyroscope signal obtained when the subject moves the head, following the test point in the screen in an oscillating horizontal way with an increasing speed. Fig 4-b shows signals obtained from 4 different subjects. A simple scaling stage is needed to adjust screen resolution and sensibility. Testing system covers linear velocity movements from ~0 pixels/sec up to 455 pixels/sec.

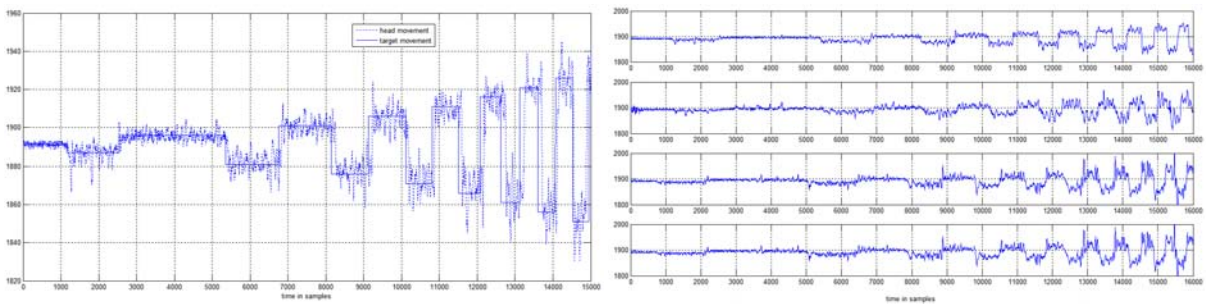

Figure 4. Gyroscope data and velocity target movement.

Amplitude and time duration of double blinking varies among different person depending on physiological characteristics and intensity of the action. A test window of 2 seconds (256 samples) starting when a mark is sent to the recording system, is processed through spectral analysis using EMD or DWT. The estimate data rate is about 20 bits/minute, based on the considered window length plus 1 second for debouncing. In the first case, using EMD, typical double blinking was found to be formed from 1 to 3 IMF and residual, as shown in figure 5. Features are obtained from the energy of each IMF and residual. The obtained feature vectors are then feed into a Mahalanobis-distance classifier. System test was performed using fold validation, dividing the data set in two groups: training and testing. Before using EMD, a preprocessing stage in the form of a simple threshold was applied to the input data in order to clean some artifacts.

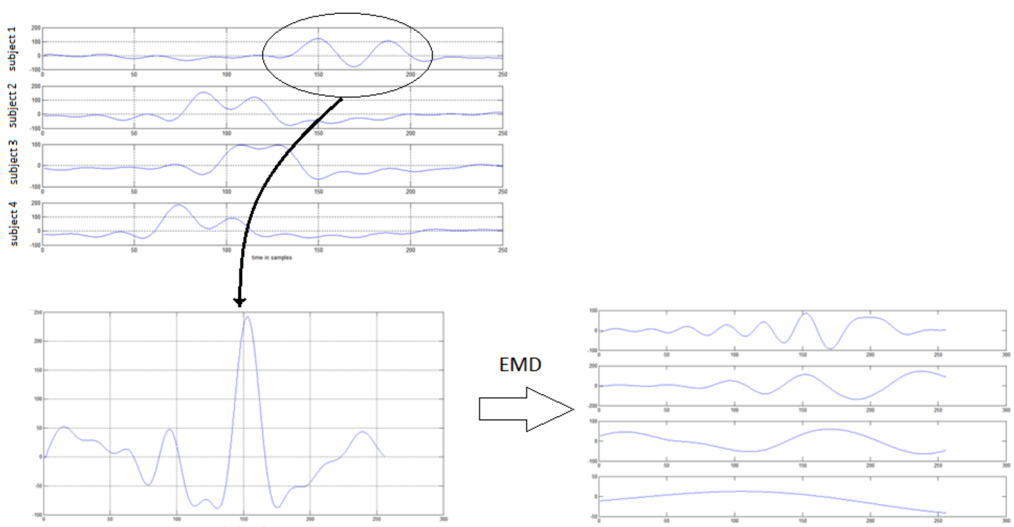

Figure 5. Typical double blinking event and its EMD representation.

The spectral analysis was performed, as a second approach, using DWT. A 5 level Daubechies-2 wavelet decomposition applied to the test window was found to be enough for providing time-scale information about the double-blinking. Wavelet decomposition typically concentrated energy at levels 2 through 5 (~1Hz to 8Hz). Power signal of each decomposition level was obtained in a similar way to the EMD case. Tables I summarizes the detection rate obtained using EMD and DWT respectively during the spectral analysis. From these results it can be seen that EMD applied on the data after thresholding performed better than DWT.

	EMD	DWT
False positive events	4.00%	2.00%
Detected	86.00%	54.00%
Absolutely undetected	10.00%	46.00%

Table I. Detection rate using EMD, and DWT spectral analysis.

Conclusions

A work in progress on the implementation of a simple EOG-based mouse using time-scale spectral analysis was described in this paper. Double blinking, which is used to emulate the mouse-clicks, is detected using spectral analysis based on Empirical Mode Decomposition and Discrete Wavelet Transform. A preliminary comparison based on the detection rate indicated that EMD provided better results, as an effective and quick computational tool. Additional experiments using larger databases, and exploring alternative preprocessing and calibration techniques are currently in progress.

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