Differentiation of signals generated by eye blinks and mouth clenching in a portable brain computer interface system.

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***Abstract*— Patients who are completely paralyzed cannot move their muscles according to their intentions. However, the majority of partially paralyzed individuals can move some of their muscles and eyes voluntarily. The monitoring of electrical activity produced by muscle movements are known as Electromyography (EMG) and the same due to eye blinks and eye movements are known as an electrooculography (EOG). Furthermore, the signals coming from EMG and EOG activities are stronger than same produced by Electroencephalography (EEG). Therefore, it is useful to have a Brain computer interface system (BCI) which operates on EMG and EOG activities in addition to EEG. The objective of this study is to investigate the distinguishability of various signals produce by EMG and EOG activities and thereby utilizing them for constructing an effective BCI system which operates according to the user intentions. Three types of EMG/EOG signals are investigated in this study. They are single eye blink, double eye blink and mouth clenching. We have developed an efficient procedure to differentiate these three activities in real time and implemented it using MATLAB. Furthermore, this efficient implementation is embedded in our Brain Computer Interface system called *GINIE*. As a result, we are able to control external lights, television sets and computer mouse 100% accurately and efficiently only using three signal types mentioned above. Also the EEG processing techniques of *GINIE* is used to generate speech commands according to the intention of the user. These features of GINIE was successfully demonstrated at the "Annual review session of National Institute of Fundamental Studies" held in March 2017.**

Keywords— BCI; CSP; EEG; LDA; EMG; EOG

I. Introduction

Brain Computer Interface (BCI) system is a direct link between human brain and external world [1]. This enables the controlling of external devices without physically interacting with them. One of the key components of BCI system is to measure brain activities. Out of several methods, because of its simplicity, most of the BCI systems use Electroencephalography (EEG) to measure the brain activities [2]. It is achieved by placing EEG electrodes on the scalp according to International 10–20 system covering the most active areas of the brain. With respect to the EEG signals, other signals produced by biological activities of the body are known as artifacts. The main artifacts of a BCI system occur due to EMG (Electromyography) and EOG (electrooculography) activities. EEG signals are usually in microvolts and EMG/EOG activities are in millivolts. Researchers worked with EEG signals usually utilize various techniques and precautions to remove and minimize these artifacts [3]. The patients who are completely paralyzed cannot move their muscles according to their intentions. Therefore, EEG based BCI system is the best solution for them to communicate with the outside world.

On the other hand, the majority of people with motor disabilities can move their various muscles and eyes voluntary [4]. The signals produced by the EMG and EOG activities are stronger than the EEG signals [5]. As a result, these electro-biological signals can be utilized for BCI systems to recognize the user intentions effectively and more efficiently as compared to the EEG based BCI systems. There are special types of electrodes and electrode placement methods to record pure EMG and EOG activities [6]. Various types of practical applications such as controlling wheel chairs and prosthetic hands have been developed, based on pure EMG and EOG signals [7]. On the other hand, EMG and EOG activities can be seen in the EEG recording as strong noise (artifacts). However, the effects on EEG signals due to EMG and EOG activities can be utilized to identify user's intentions more accurately.

The objective of this study is to develop a BCI system which works well with EEG signals as well as EMG/EOG signals without changing the electrode arrangement. In this study we focused on three types of EMG/EOG signals. They are single eye-blink, double eye-blink and mouth clenching. The same EEG electrode cap and the recording system were used to capture these signals. Further we have developed an efficient algorithm to distinguish these three signals effectively and used to control physical devices according to the user intention with our portable BCI system, *GINIE*.

II. Methodology

A. Hardware design

An eight channel wireless EEG amplifier and an electrode cap were used to record EEG in this study. The wireless EEG amplifier and the electrode cap were designed and constructed at our NIFS laboratory. The EEG amplifier, which amplifies the bio signals and converts it to digital format, was constructed based on ADS 1299 IC manufactured by Texas Instruments. The high input impedance of the amplifier (1000 MΩ) ensures the minimum effect on the measuring subject. It consists of eight analog input channels and the gain of each channel can be set to pre-defined values: 1, 2, 4, 6, 8, 12, or 24. The common mode rejection ratio of the amplifier is in between 110 -120 dB which indicates the higher capability of rejecting the common mode signals from inputs such as line noises. The ADS 1299 chip consists of 24-bit Analog to Digital Converters (ADC) for each individual channel with reference voltage of 4.5 V. Therefore, the ADC is able to detect voltage change of 0.26 µv of the input signal. As a result, the amplifier is capable of measuring various types of bio potentials such as EEG (Electroencephalography), EOG (electrooculography) and EMG (Electromyography). The sampling rate of ADC can be programed from 250 SPS (Samples per second) to 16 k SPS. 250 SPS sampling rate is more than enough for the reconstruction of signals as the interested band of bio potential signal is between 1 Hz – 30 Hz. An Atmega328p microcontroller was used to control the overall functionalities of the amplifier and transmit captured data to the controlling computer via Bluetooth. The electronic components of the amplifier system and the Bluetooth module are compacted on a low noise dual sided printed circuit board (PCB). The amplifier system is powered by a 3800 mAh Li – Iron battery.

The electrode cap was constructed to hold eight Dry EEG electrodes (according to the international 10 -20 system), amplifier and the battery. This compact arrangement made the system portable and capable to use same set of electrodes to measure EEG, EOG and EMG signals. This system was named as *GINIE*. Fig 1 shows an image of the portable BCI system.

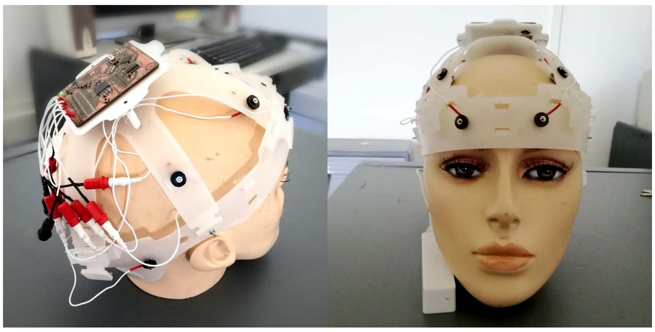
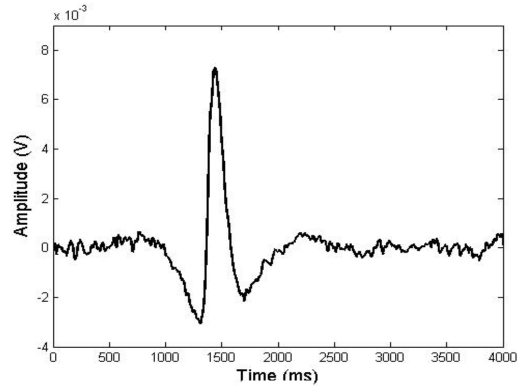


Fig. 1. The portable BCI system, GINIE. The amplifre circitry is placed on the electrod set and the system is powerd by a 3800 mAh Battery.

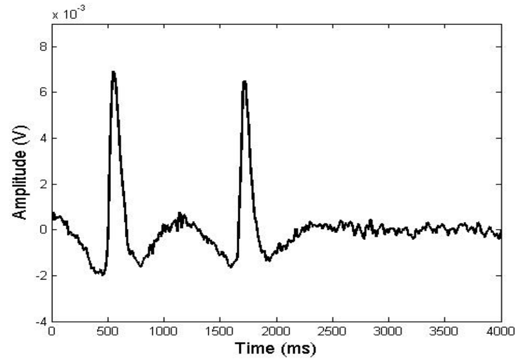
B. signal identification

Most of the patients who are partially paralyzed can voluntary move their muscles and eyes. As a result, they can produce different types of EOG and EMG signals according to their intentions. Unlike EEG signals, changes in EOG and EMG signals are easy to identify visually.

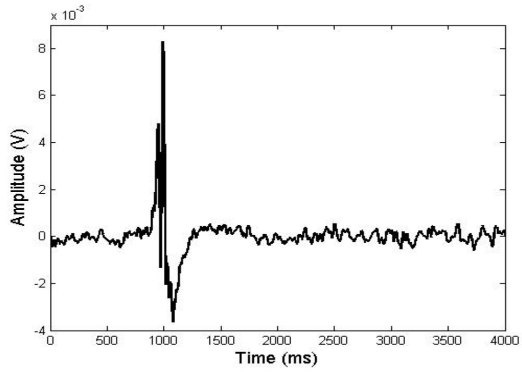
However, due to their similar nature, distinguishability of EOG and EMG signals is not a straight forward process. Therefore, in order to use them in a BCI system, it is important to distinguish these signals efficiently and accurately in real time. GINIE was designed to perform several functionalities based on three types of EMG and EOG signals. They are single eye-blink, double eye-blinks and mouth clenching. Fig 2 shows these three types recoded using *GINIE*.



(a)



(b)



(b)

Fig. 2. EMG and EOG signals recorded from GINIE. (a) Single Eye Blink , (b) Double Eye Blink , (c) Mouth clenching

According to the figures, it is clear that amplitude of the mouth clenching signal goes to positive region at the beginning. On the other hand, both eye-blink signals go to negative region instead. This property was used to identify the mouth clenching from the eye blinks efficiently because it requires analyzing only the starting region of the signal to take the correct decision. However, it was difficult to use the same property to separate double eye blinks from a single eye blink. Several methods are available to address this problem. One reliable method is to count the number of peaks of the signal with a threshold value. This method produces 100% correct decision. But it is inefficient because it requires analyzing the complete sample points of the signal in real time. In order to make the identification as well as distinguishing of the signals due to single eye blink and double eye blinks efficiently, we have implemented the following procedure.

- Since the built in *max* function of MATLAB is very efficient, it can be used to identify idle situations as compared to eye blinks or mouth clenching.
- When it is identified that there is a mouth clenching or eye blinks in the signal, mouth clenching signal can be differentiated from the eye blinks as described earlier.
- In order to differentiate a single eye blink from double eye blinks, the following procedure is followed. Starting from time t=0 each sample point of the signal is tested against a threshold value to determine whether a peak is encountered. After each sample point is tested, the value of it is changed to zero. This procedure is continued until the first maximum is identified. Even after reaching the maximum, we continue to zero sample points until the value of the signal reached below the threshold value again.
- Now the maximum of the modified signal is found using max function and compared it with the threshold value to determine whether there is a second peak.
- Since max function built in the MATLAB is very efficient, it is found that above mentioned method is comparatively much more efficient than just directly finding the two peaks.

Above mentioned method is particularly useful for partially paralyzed individuals. However, the situation for totally paralyzed patients is different. They cannot move their muscles or eyes voluntary. The only way to identify their intensions is the use of EEG. Distinguishing EEG signals for different kind of thoughts is not as simple as same for the EMG or EOG. It requires various signal processing methods to analyze EEG signals.

C. *Software*

The software was designed and implemented using MATLAB GUI and it is capable of analyzing EEG, EMG / EOG signals and identifying the user's intentions.

When the system operates on EMG/EOG signals, it uses only one EEG electrode (placed on the frontal lobe) of the electrode cap to receive the signals. The identification of the single blink, double blinks and mouth clenching was based on the idea which is described in the previous section. This idea was implemented to control external lights, a Television and a computer mouse. We observed 100% efficiency using this method.

Identifications based on EEG involve three stages. Pre–processing stage, Feature vector construction stage, Classification stage and Post processing stage. At the pre–processing stage, EEG data is filtered and artifacts are removed. Each EEG channel was filtered with 50 Hz notch to cut off the line noise. Thereafter a 3rd order forward-backward Butterworth band pass filter was used to filter out unwanted contaminations from the data. Cut-off frequencies were set to 1 Hz and 30 Hz. In the next stage, feature vectors are constructed by using various signal processing methods. For the feature vectors construction, the most effective method we found is Common Spatial Patterns(CSP) [8]. At the classification stage, feature vectors are classified using classification techniques. We found Linear Discriminant Analysis (LDA) [9] as the most reliable classification method for this system. We used EEG to select and play various prerecorded speech commands which are important for a fully paralyzed patient. Figure 3 shows the screen capture of the software.

Fig. 3. : The software interface of GINIE. It has options to operate based on EEG signals as well as EMG/EOG.

III. Concluding Remarks

Both the hardware and the software of *GINIE* were designed and constructed at NIFS. Wireless nature of GINIE made the system very comfortable to use. The identification of single eye blink, double eye blinks and mouth clenching was 100% efficient using the method described in previous sections. Various features of the portable BCI system (GINIE) was demonstrated at the "Annual review session of National Institute of Fundamental Studies" held in March 2017. We have controlled the main lights of the auditorium using the combination of single blink and the mouth clenching signals. Then an external television set was controlled using the combination of single blink and the double blinks signals (TV On/Off, Volume UP/Down, Channel UP/Down). On the other hand, all three signals, single eye blink, double eye blinks and mouth clenching signals, were used to control the mouse pointer of an external computer and execute programs in that machine. Finally, the EEG signals were used to select and play sentences in Sinhala according to the user intentions.

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