Steady State Visual Evoked Potential Based Thought Translation Device

Jayesh Malik
SGSITS, 23, park road, Indore, 452003, M.P.
jay_biomed06@yahoo.co.in

Sakshi Bansal
SGSITS, 23, park road, Indore, 452003, M.P.
sakshi_bme@yahoo.co.in

Priyanka Gupta
SGSITS, 23, park road, Indore, 452003, M.P.
priyanka.bme@gmail.com

Yajuvendra Rathore
SGSITS, 23, park road, Indore, 452003, M.P.
yaj_rathore@yahoo.co.in

Abstract- This paper introduces a system that can help the disabled persons, who have no motor control left for communication besides eye movements, to achieve an acceptable level of communication. The system incorporates a brain-computer interface (BCI) for connecting the brain to the computer. Steady-state visual evoked potentials (SSVEPs) recorded from the occipital scalp are used as the input of our BCI system. SSVEP-based BCI is essentially EEG-based vision-tracking system. This system relies on the user's ability to control eye movements. The frequency-coded SSVEPs elicited by multiple flickered visual stimuli can be used to determine where the eyes are directed. Twenty-eight buttons illuminated at different rates were displayed on a computer monitor. The buttons constituted a virtual keypad, representing the 26 alphabets from A-Z, BACKSPACE, and ENTER. Users could input alphabets by gazing at these buttons. The frequency-coded SSVEP was used to judge which button the user desired. The attractive features of the system are noninvasive signal recording, little training required for use, and high information transfer rate.

1 INTRODUCTION

A brain-computer interface (BCI) is a communication channel connecting the brain to a computer or another electronic device. The intrinsic feature of a BCI is that it does not depend on the brain's normal output pathways of peripheral nerves and muscles. Two basic requirements are met for a communication channel between the brain and computer:

1) Features that are useful to distinguish several kinds of brain state,
2) Methods for the detection and classification of such features implemented in real time.

Various techniques are now available to monitor brain function, e.g. electroencephalography (EEG), magneto encephalography, functional magnetic resonance imaging, and positron emission tomography. The latter three techniques are technically demanding and expensive. At present, EEG is the optimal choice for BCI implementation. These systems differ greatly in their inputs, feature extraction and translation algorithms, outputs, and other characteristics such as speed, accuracy, and appropriate user population. Typical input signals of BCIs include slow cortical potentials, or rhythms recorded over sensorimotor cortex EEG patterns associated with different mental tasks, and visual evoked potentials (VEPs). Electrodes can be placed either on the scalp or on the cortex. Typical BCI applications involve cursor movement, letter or icon selection, or device control. Currently, BCIs are mainly used as augmentative communication technology for individuals with motor impairments, such as amyotrophic lateral sclerosis (ALS) or cerebral palsy. Several issues are crucial to further development and expanded utilization of the BCI technology. The first issue is the information transfer rate. The second issue is the training time for users to develop competence. The third issue is medical invasiveness. The less invasive the technique the more likely it can be used in a wide range of applications. Based on the above considerations, our interests concentrate on the high transfer rate, minimal training, and noninvasiveness. Steady-state visual evoked potentials (SSVEPs) recorded from the occipital scalp are used as the input of our BCI system. The system has the advantage of focusing on EEG activity that occurs at a specific frequency. This feature simplifies the feature extraction methods, and users require little or no training. SSVEP-based BCIs belong to dependent BCIs. An intact visual system is necessary, and it will be wholly devoted to EEG-based communication. We have applied SSVEP-based BCI to control cursor movements. In that work, four buttons illuminated at different frequencies represented four directions; users could move the cursor to different directions simply by looking at the corresponding buttons. In this paper, we will introduce a new application of SSVEP-based BCI to show the system's ability to provide high transfer rates.

PRACTICAL ASPECTS OF SSVEP

Definition

The visual evoked potential (VEP) is defined as the electrical response, evoked by visual stimulation, from neurons in the visual cortex. It can be recorded through electrodes affixed to the scalp. A transient VEP is obtained when the stimulus rate is low and the response is recorded over one single stimulus cycle. A steady-state VEP (SSVEP) is defined as a repetitive response to a stimulus repeated with higher frequencies, and ideally contains discrete frequency components that remain constant in amplitude and phase over an infinitely long period. In clinical practice the use of a transient VEP response to a flash or a check stimulus is most common. The amplitude and the latency of the response are the most important parameters to evaluate, but the shape of the VEP complex may also carry information. The configuration of a normal VEP can vary considerably, depending on several factors, e.g. age and stimulus, the attentiveness of the subject or the positions of the electrodes.

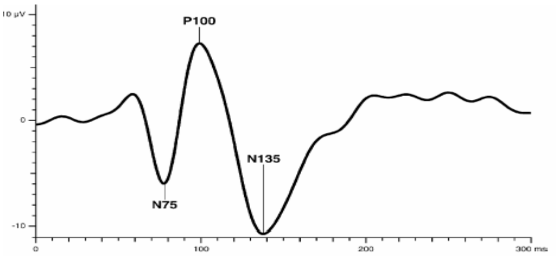


Figure 2. A normal pattern reversal VEP.

2 BCI COMPONENTS

A typical BCI device consists of several components. These include electrode cap, EEG amplifiers, computer and subject’s screen. A critical issue is how the user’s commands, i.e., the changes in the EEG are converted to actions on the feedback screen or the application.

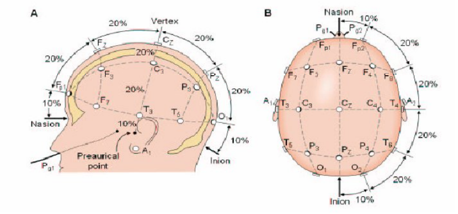
This process can be divided into five stages:

1) Measurement of EEG

It is done by using the electrodes. Many BCIs use a special *electrode cap*, in which the electrodes are already in the right places, typically according to the international 10-20 systems. It saves time because the electrodes do not have to be attached one by one. Typically, less than 10 electrodes are used in online BCIs with sampling rates of 100-400 Hz.

2) Preprocessing

This includes amplification, initial filtering of EEG signal and possible artifact removal. Also A/D conversion is made, i.e. the analog EEG signal is digitized.



3) Feature extraction

In this stage, certain features are extracted from the preprocessed and digitized EEG signal. In the simplest form a certain frequency range is selected and the amplitude relative to some reference level measured. Typically the features are certain frequency bands of a power spectrum. If the feature sets representing mental tasks *overlap* each other too much, it is very difficult to classify mental tasks, no matter how good a classifier is used. On the other hand, if the feature sets are distinct enough, any classifier can classify them.

4) Classification

The features extracted in the previous stage are the input for the classifier. Different BCIs can classify different number of classes, typically 2 to 5 classes. The classifier can be anything from a simple linear model to a complex nonlinear neural network that can be trained to recognize different mental tasks. With the exception of a simple threshold detection, the classifier can calculate the probabilities for the input belonging to each class. Usually the class with the highest probability is chosen. However, in some BCI protocols none of the classes may be chosen, if the classification probability does not exceed some predefined level. This kind of classification result can be called “nothing” or “reject”.

5) Device control

The classifier’s output is the input for the device control. The device control simply transforms the classification to a particular action. The action can be, e.g., an up or down movement of a cursor on the feedback screen or a selection of a letter in a writing application. However, if the classification was “nothing” or “reject”, no action is performed, although the user may be informed about the rejection.

3 FEEDBACK

Feedback is an important factor in BCIs. In the BCIs based on the operant conditioning approach, feedback training is essential for the user to acquire the control of his or her EEG response. The BCIs based on the pattern recognition approach and using mental tasks do not definitely require feedback training. However, feedback can speed up the learning process and improve performance. Cursor control has been the most popular type of feedback in BCIs. Feedback can have many different effects, some of them beneficial and some harmful. Feedback used in BCIs has similarities with *biofeedback*, especially EEG biofeedback. EEG MECHANISM Electroencephalography (EEG) is a method used in measuring the electrical activity of the brain. This activity is generated by billions of nerve cells, called *neurons*. Each neuron is connected to thousands of other neurons. Some of the connections are excitatory while others are inhibitory. The signals from other neurons sum up in the receiving neuron. When this sum exceeds a certain potential level called a *threshold*, the neuron fires *nerve impulse*. The electrical activity of a single neuron cannot be measured with scalp EEG. However, EEG can measure the combined electrical activity of millions of neurons. The temporal resolution of EEG is very good: millisecond or even better. However, the spatial resolution is poor. It depends on the number of electrodes, but the maximum resolution in centimeter range whereas, for example, in MEG, PET or fMRI it is in millimeter range. The ongoing EEG is characterized by amplitude and frequency. The amplitudes of the EEG signals typically vary between 10 and 100 _V (in adults more commonly between 10 and 50 _V). The electrical activity goes on continuously in every living human's brain. We may sleep one third of our life times, but the brain never rests. Even when one is unconscious the brain remains active. Much of the time, the brain waves are irregular and no general pattern can be observed. There exist various properties in EEG, which can be used as a basis for a BCI:

1. Rhythmic brain activity
2. Event-related potentials (ERP's)
3. Event-related de synchronization (ERD) and event-related synchronization (ERS).

Band	Frequency [Hz]
Delta (δ)	< 3.5
Theta (θ)	4-7.5
Alpha (α)	8-13
Beta (β)	>13

Common EEG frequency ranges

Depending on the level of consciousness, normal people's brain waves show different rhythmic activity. For instance, the different sleep stages can be seen in EEG. Different rhythmic waves also occur during the waking state. These rhythms are affected by different actions and thoughts, for example the planning of a movement can block or attenuate a particular rhythm. The fact that mere thoughts affect the brain rhythms can be used as the basis for the BCI.

The EEG can be divided into several frequency ranges as displayed in the above table. These ranges set the limits in which the different *brain rhythms* can be observed.

EEG BIOFEEDBACK

The basic idea in the EEG biofeedback is the operant conditioning of certain EEG parameters. Typically, the goal of the training is to increase the activity on a certain frequency band and decrease it in another. This is possible by providing feedback for the subject. The feedback can be, for example, a car in the computer game. The speed of the car can be coupled with the desired condition. The car moves faster, if the patient's EEG gets closer to the desired condition and slower, if it gets farther. Generally, biofeedback methods used in the clinical EEG biofeedback have been much more imaginative than in BCI systems. Whereas in the BCI systems the feedback is in the form of the cursor control in almost all cases, the feedback in EEG biofeedback has included various kinds of games and visual displays.

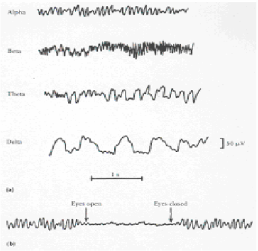


Figure 2.3: (a) Examples of alpha, beta, theta and delta rhythms. (b) Effect of eye opening in the alpha rhythm

In addition to visual feedback, auditory and tactile feedback has also been used. The EEG biofeedback is closely related to the operant conditioning approach in BCIs. In fact, the self-regulation of the slow cortical potentials have been used with patients having neurological and psychiatric disorders, for example, untreatable chronic epilepsy. Today, a BCI called Thought Translation Device is based on self-regulation of SCPs. However, there is fundamental difference between the use of BCI and typical EEG biofeedback treatment. In biofeedback treatment the goal is to reach certain condition and maintain it, whereas in BCIs the goal is that the user learns to 21 change his or her EEG between two or more conditions.

FEEDBACK IN BCI

In most BCIs some kind of feedback is provided to the user. The most popular form of feedback has been the cursor control. In a typical *trial*, the user tries to move the cursor to the target, which is located on one side of the screen by using two commands (i.e., up & down or left & right). At the start of the trial the cursor is at the middle of the screen. The trial ends when the cursor hits either the target or the opposite end of the screen. If the target side of the screen is hit, the target can be flashed to indicate the trial outcome. One trial typically lasts a few seconds. After the cursor has hit the target, it blinks and a smiley face saying “very good” appears as a *positive reinforcement*. Why has the cursor control been such a popular type of feedback in BCIs? One reason may be that the goal of many BCI research groups is to give the user, a disabled person, an opportunity to operate an ordinary personal computer by thoughts. In addition to this, there may be other reasons. The cursor control is an example of *continuous* feedback.

An example of feedback display used in the TTD. After the balllike cursor has successfully hit the target, a smiley face appears as a positive reinforcements.

EFFECT OF BIOFEEDBACK

In BCIs using the operant conditioning approach, the feedback about the performance is essential in *skill development*, i.e., in acquiring control over the EEG response. The subject needs to know which imagery moves the cursor up and which imagery down.

Beneficial effects

1. Furnishes continual motivation
2. Ensures attention to the task by maintaining the subject’s interest
3. Improves performance by allowing rapid reaction to wrong classifications

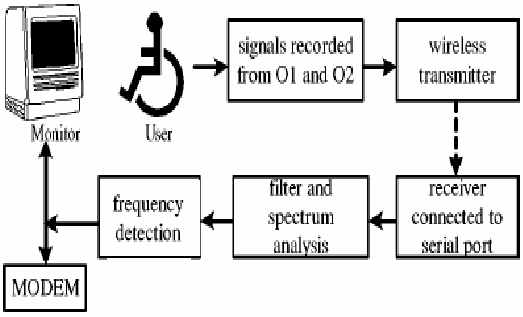
4 METHODS

A. Scientific Background

VEPs reflect the electrophysiological mechanisms underlying the processing of visual information in the brain. The signals are always in response to changes in the stimulus. A static stimulus in the visual field does not appear to effect any significant alterations in EEG activity. The signals evoked by changes in the visual input have been shown to reflect certain properties of the stimulus. A distinction is made between transient VEP and SSVEP based on the stimulation frequency. The former arises when the stimulation frequency is less than 2 Hz. If the repetition rate of the stimulus is higher than 6 Hz, however, a periodic response called the SSVEP will result. It is composed of a series of components whose frequencies are exact integer multiples of the repetition frequency. The amplitude and phase of the SSVEP are highly sensitive to stimulus parameters such as repetition rate, contrast or modulation depth, and spatial frequency. The SSVEP was found to be strongly dependent on spatial attention, being substantially enlarged in response to a flickering stimulus at an attended versus an unattended location. The increased SSVEP amplitudes reflect an enhancement of neural responses to a stimulus that falls within the range of spatial attention. This observation shows that SSVEP may provide an on-line method to identify the attentional target among a group of stimuli.

B. Hardware and Software

Figure shows the block diagram of the SSVEP-based BCI system. The system was designed to help users to express his thoughts. Twenty-eight buttons that flickered on and off at different frequencies were displayed on a computer monitor. The on-off duty cycles were 50/50 for all frequencies. The 4 X 7 stimulus matrixes constituted a virtual keypad, representing the alphabets, BACKSPACE, and ENTER. Users could input alphabets and correct input errors by gazing at these buttons. A beep was sent out from the loudspeaker of the computer after each selection, and the result was displayed on the monitor so that users could know whether the selection was correct.



Block diagram of the SSVEP-based BCI system for expressing the user's thought

If the selection was wrong, users could delete it by gazing at the button BACKSPACE. When ENTER was selected, the input alphabet would be displayed. The button ON/OFF was designed to control the start and stop of the other stimuli. It would be flickered all the time. If the stimulus matrix was static, the system only needed to detect the frequency of the button ON/OFF. A rigorous detection criterion was applied to this button to reduce the occurrence of false positives. The buttons were widely spaced on the screen. Each button was a 2 cm 2.7 cm rectangle. Two-channel EEG signals were recorded from O_1 and O_2 according to the international 10–20 system and referred to the left and right ear lobes respectively. The electronic circuits provided signal amplification, A/D conversion (sampling rate 200 Hz), and signal transmission. A wireless transmitter was adopted in the system to give users more freedom. Users could move their heads freely as long as their eyes were fixed on the desired buttons. A receiver connected to the serial port provided input data to the computer. The data were filtered with a band pass of 4–35 Hz.

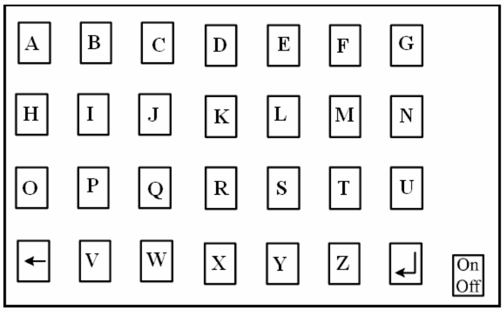


Fig. Twenty Eight buttons widely spaced on the screen of a computer monitor.The 4 X 7 stimuli matrix constituted a virtual keypad including BACKSPACE & ENTER.The button ON/OFF was designed to control the start and stop of the other stimuli.

5 DISCUSSION

A. Information Transfer Rate

The transfer rate of a BCI system depends on three factors: number of selections, accuracy and speed. Currently, many BCIs are designed to control one-dimensional or two-dimensional cursor movements. Only two or four EEG patterns are needed for this kind of task. It is relatively simple to increase the number of selections in VEP-based BCI systems. One trained subject with implanted electrodes can reach communication rates of 10–12 words/min. In our system, each trial had 28 possible selections, which was crucial to the realization of high transfer rates.

B. Appropriate Applications

SSVEP-based BCIs are essentially EEG-based vision- tracking systems. These systems rely on user's ability to control eye movements. This prerequisite restricts the possible applications. It might not be effective, e.g., for some severe ALS patients. The subjects could move their heads and blink freely in the experiments, but they should concentrate on the tasks. We have observed that the input accuracy would decrease when the subject was listening to other people's conversation.

C. Use of MODEM

Here MODEM is connected with the computer monitor. By using MODEM user can interact with the outside world through INTERNET.

D. Comparison with on screen Keypad

Virtual Keypad works in the same way as that of an on-screen keypad with the difference that in on screen keypad the input is through mouse but in virtual keypad, the input is given by gazing at the desired button.

6 CONCLUSION

The frequency-coded SSVEP's elicited by multiple flickered visual stimuli can be used to determine where the eyes are directed. This methodology was used to construct a BCI system that could help users to input phone numbers. Users could operate the system with little training. A higher performance can be expected when using more visual stimuli and more sophisticated signal processing methods, optimized for each user individually.

7 ACKNOWLEDGEMENT

There are many disabled persons who have no motor control left for communication besides eye movements. The system introduced in this paper can help them to achieve an acceptable level of communication. Future systems will reduce the dependence on a general-purpose computer. For example, LED's can be used in the stimulus device, and data analysis can be realized in special digital signal processor. The practical system will be compact and portable.

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