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Low-cost evoked potentials detection for brain computer-interfaces

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Evoked potentials are one of the brain's electrical activity types. They appear on the human scalp as a result of a registration of an external stimulus (e.g. an appearance or a change of a sound, a flash of light or an image). Generally, they are used in medical diagnosis, but they also may be used in brain-computer interfaces. In this chapter a laboratory set for the acquisition and analysis of evoked potentials is described. The main part of this set is a photostimulator consisting of sixteen LEDs and the ATmega 328 microcontroller. The software created by the authors allows for: connection between EEG device, stimulator and computer, input stimulus control, output signal filtering and its classification. The presented set may support a process of brain-computer interface design.

KEYWORDS: brain-computer interface, detection of evoked potentials, EEG, signal processing, MATLAB

1. Introduction

A brain-computer interfaces (BCIs) can be used for direct communication between a brain and a computer, without using muscles [3]. Nowadays they help primarily people with so-called locked-in syndrome, the disease where a patient is conscious but in a vegetative state. BCIs may be very useful for paralyzed people to communicate with surrounding environment. These devices are also used in other applications such as the entertainment, industry or military needs.

BCIs merge such fields as biomedical engineering, advanced signal processing, artificial intelligence and neuroscience. Appropriate analysis of bioelectrical signals used in BCI is the most common as well as the most difficult problem in biomedical engineering. Proper selection of the measurement procedures makes it possible the reliable acquisition and processing of the major parameters of the measured signals and the significant limitation of factors affecting processed signals.

1.1. Evoked potentials

Non-invasive brain-computer interfaces use the electroencephalography (EEG) to measure such interesting brain activity reactions as the evoked potentials. The advantages of that method are: high resolution time, a simple signal acquisition and lower unit costs compared to other methods of monitoring the brain activity i.e., magnetoencephalography, near-infrared spectroscopy, positron emission tomography and functional magnetic resonance imaging. The measurement is performed with electrodes placed on the head by the use of a special cap. Measured signals are transferred from the electrodes to an electroencephalograph.

Evoked potentials are spontaneous brain reactions. They appear on the scalp as a result of a registration of an external stimulus. An example of such stimulus can be: an appearance or a change of a sound, flashing lights or an image, or a reaction of the sense of touch [5, 11].

One of the simplest phenomena used in brain-computer interfaces are Steady State Visual Evoked Potentials (SSVEP). If a given person focuses his/her attention on the flashing (with specified frequency) stimulus shown on the computer screen, a signal of the same frequency will appear in his or hers visual cortex and from there it will be measured. When there is more than one stimulus on the screen and each flashes with a different frequency, then being basing on the analysis of the signal, we can conclude, on which the given person looks from surrounding objects [12].

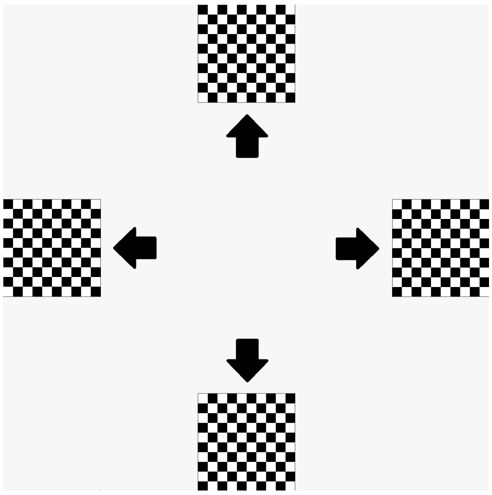
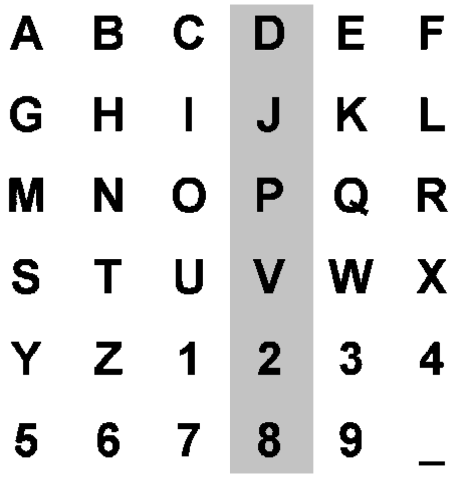


Fig. 1. Computer screen during SSVEP examination

In BCIs light stimuli are generated in two different ways. In the first one, stimuli are usually presented on a computer screen as a flashing checkerboard or the squares. An example of that solution is presented in Figure 1. In the second way, various sets of LEDs are used. Each set is flickering at a different frequency [4, 9].

In another type of BCIs potentials the P300 is used. This brain electrical response can be found when an expected stimulus is occurring. It appears about 300 ms after its occurrence [13, 14]. These interfaces are based on flashing visual stimuli (letters or symbols). They represent the directions and allow to control the robot or the cursor on the computer screen.

An example of interface in which user observed randomly illuminated fields containing letters is shown in Figure 2. When the "expected" box (where the user’s attention is focused) is highlighted, at the top of the head the P300 response appears. In a single measurement that phenomenon cannot be observed, so it is important to focus the attention several time on a the selected stimulus to average the results (separately for vertical and horizontal). The letter, which the subject is focused on, is located at the intersection of the two line selected by the interface [3].



A	B	C	D	E	F
G	H	I	J	K	L
M	N	O	P	Q	R
S	T	U	V	W	X
Y	Z	1	2	3	4
5	6	7	8	9	_

Fig. 2. Computer screen during P300 examination

2. Laboratory set

The laboratory set consists of three basic elements: an EEG, a photostimulator and a computer with software written in MATLAB.

2.1. Software

Software block diagram is shown in Figure 3. Each examination begins with mounting EEG electrodes on user's head. After starting the device, a connection between EEG and computer is established using Bluetooth. When a computer receives the information about the successful connection, a connection to the photostimulator starts. If this connection is established, the system is ready to receive and store data from EEG.

During the examination, the system sends information to photostimulator about stimulus which should be displayed in a specific moment. That information contains the flashing frequency and the stimulus duration. Moreover, the software is adding to the file with data information about the moment when stimulus was shown. It is important for further analysis to identify as precisely as possible the begin and the end of the exposure of the stimulus.

2.2. Photostimulator

A photostimulator was built for the presented brain-computer interface. It consists of 16 LEDs, each with a diameter of 5 mm. LEDs are arranged at equal intervals on the shape of a square which side is 100 mm. It is possible to select a color of LEDs: green, red, yellow, blue and white.

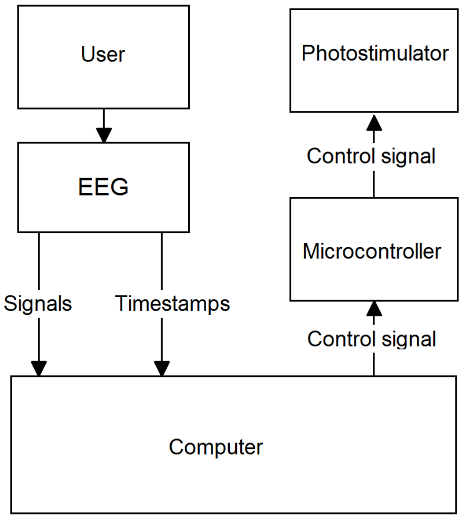


Fig. 3. Software schema

A microcontroller ATmega 328 is used for LED control and communication with the computer.

The photostimulator can operate in two modes, depending on which type of evoked potentials is examined at the moment. In the first mode, which can be used for SSVEP, all LEDs are flashing at a selected frequency in the range from 1 to 50 Hz. In the second mode, which can be used for P300, in a specific moment only one line (horizontal or vertical) of LEDs is highlighted for 50 to 500 ms.

3. Signal processing

After examination, the obtained signals are available in MATLAB as variables. Each variable corresponds to the signal from one electrode. Our software provides the ability to analyze two types of evoked potentials: P300 and SSVEP.

In the first stage of processing timestamps are added to the collected data. Next, the unnecessary parts of the signal formed at the beginning and at the end of the test, when the photostimulator was not running or in the time between stimuli, are deleted.

The method of further signal processing is dependent on the analyzed evoked potential. Presented set is recommended for SSVEP. SSVEP obtained in our research was presented in Figure 4.

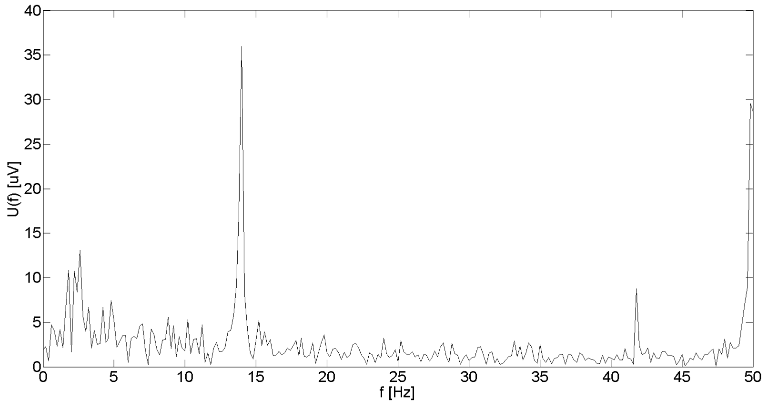


Fig. 4. Response to 14 Hz stimulus

In our SSVEP research the signal is filtered by the bandpass Butterworth filter in range from 8 Hz to 48 Hz and by the AMUSE - Blind Signal Separation (BSS) algorithm [1, 8, 10]. For the classification the Canonical Correlation Analysis (CCA) is used [6, 2, 7]. That method is very often applied in SSVEP BCI. Signal processing schema is shown in Figure 5. The results of the use of this method in our research are illustrated in Figure 6.

In an implementation of this method for the purposes of BCI the correlation between measured signal and reference signals are compared. If stimuli flashes with two different frequencies, for example 10 Hz and 20 Hz, algorithm creates two groups of reference signals. First group would be consist of a 10 Hz and next harmonics. The second group includes the same signals, but the fundamental frequency would be 20 Hz. In that method the correlation (r-Pearson) between the reference signal and the EEG signal is calculated. System decides that the subject looks at the stimulus that obtained greater correlation.

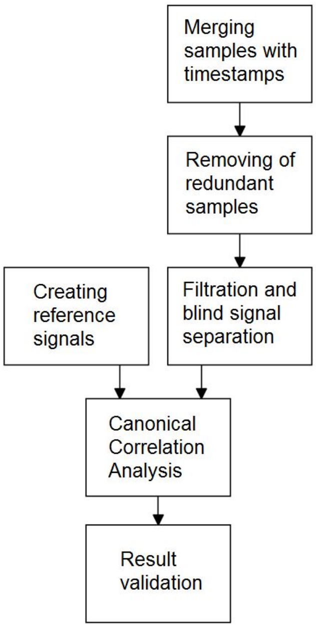


Fig. 5. Signal processing schema

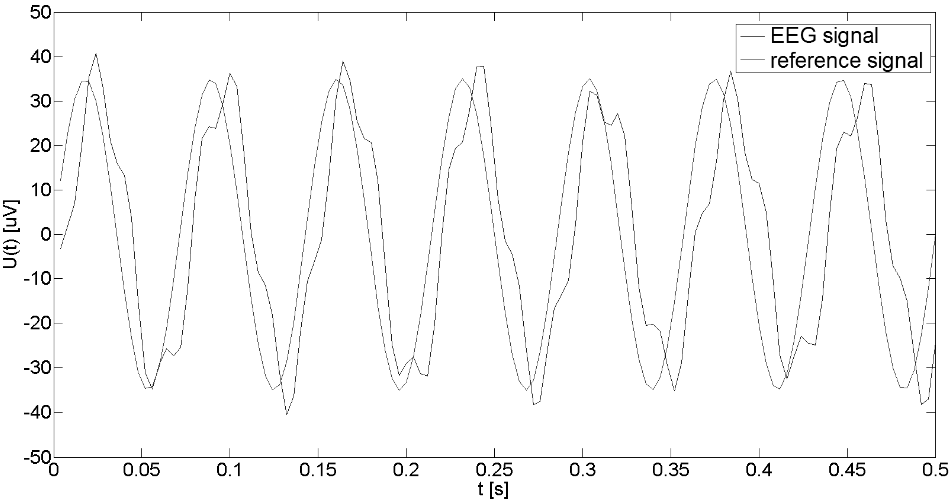


Fig. 6. Canonical Correlation Analysis: a response to 14 Hz stimulus

Each of the signal fragments is compared with each of the reference signals. The number of reference signals depends on the number of stimuli. Reference signals are created with a sine of a frequency range from 10 Hz to 46 Hz.

Figure 7 shows the result of a single test. The subject looked at flashing LEDs for 5 seconds. Every time another stimulus was presented (with a different fundamental frequency). On the spectrogram obtained from the EEG signal, dark lines indicate the moment when stimulus was shown.

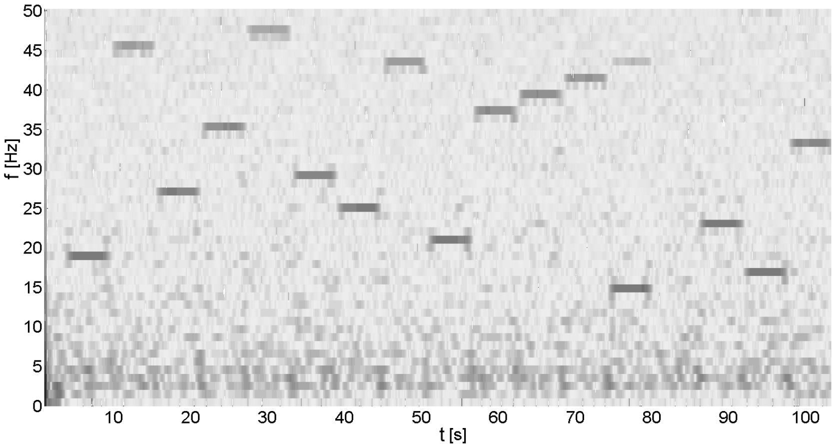


Fig. 7. Spectrogram: results for 10 Hz to 46 Hz stimulus

To analyze the phenomenon of P300 an uncomplicated method is used [15]. This method is based on averaging a signal for each diode and then determining the sum of the ratio of samples collected in the intervals of time between 250 and 550 ms, and between 600 and 900 ms. The LED with the highest value is a diode the subject was looking at. Figure 8 shows the result of our own studies showing the effect of P300.

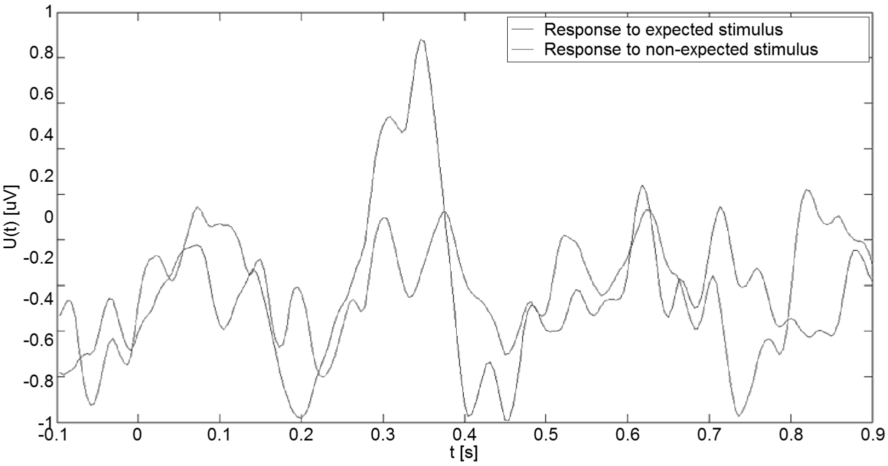


Fig. 8. P300 response

For signal classification machine learning algorithms like SVM (Support Vector Machine), LDA (Linear Discriminant Analysis) or artificial neural networks are preferred. Using the results from these machine learning algorithms the system on its own decides which stimulus the subject is looking at.

5. Conclusion

The chapter presents laboratory set for measurement and analysis of evoked potentials. The important advantage of the presented solution is a universal photostimulator which can cooperate not only with simple electroencephalographs, but also with devices dedicated for neuroscience research such as StimTracker. Another advantage is that the presented hardware and software can work in different modes, which greatly facilitate the preparation of brain-computer interfaces. The use of MATLAB software is also good point: this leading tool for advanced engineering calculations allows relatively easy further extension of the presented set.

The obtained results are very promising. The subject work of the planned future work will be an attempt to create a brain-computer interface that uses the phenomenon of SSVEP and presented set. Authors suggest to check other blind source separation algorithms or to use extended versions of CCA, such as MsetCCA or L1MCCA to provide more effective recognition of the stimulus.

Modern technology determines the directions in the development of current biomedical engineering, making it possible to spread into areas that were up to now inaccessible. Design and implementation of BCIs is one of the major challenges of modern science and technology. Possibility of the direct human-computer interaction, without using limbs, opens new channels of communication in many contemporary fields of applications.

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