Simple communication using a SSVEP-based BCI

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Abstract. Majority of Brain-Computer Interface (BCI) for communication purposes are speller, i.e., the user has to select letter by letter. In this work, is proposed a different approach where the user can select words from a word set designed in order to answer a wide range of questions. The word selection process is commanded by a Steady-state visual evoked potential (SSVEP) based-BCI that allows selecting a word in an average time of 26 s with accuracies of 92% on average. This BCI is focus in the first stages on rehabilitation or even in first moments of some diseases (such as stroke), when the person is eager to communicate with family and doctors.

1. Introduction

According to statistics from the World Health Organization (WHO), there are in the world about 10% of people with permanent disabilities (motor, sensory, mental, and others), i.e., about 600 million people suffer some form of disability [1]. In particular, people suffering severe motor disabilities due to high cervical injury, cerebral palsy, multiple sclerosis or muscular dystrophy, have multiple consequences for all their neuromuscular system. These sequels prevent the person from proper communication with their environment.

A brain computer interface (BCI) is a communication system that can generate control signals from the brain activity. These are obtained directly by an electroencephalogram (EEG), without using any muscle [2].

Over the past two decades several studies have evaluated the possibility that EEG signals may create a new technology trend that does not require any effort. Thus, a subject can establish an interaction with the outside world, either by sending messages or commands without muscular activity, [3].

Different electrophysiological experiments have shown that neurons in the visual cortex are synchronized with the frequency of a flashing light [4], generating in the EEG responses showing the same frequency as the light stimulus [5].

In this work, a BCI based on Steady-State Visual Evoked Potentials (SSVEP) was used in order to select a word from a predefined set of words, in a fast and robust way. This BCI allows a person to express a word quickly, instead of typing letter by letter as in [7] or [8], which can result in a longer process and tiring for the user. This approach is focus in the first stages on rehabilitation, when an easy, no stressed and fast communication between patient and physician is needed.

2. EEG database

The BCI was implemented to allow simple communication. Hence, three lights were set on the sides of a computer monitor: two flashing bars of 10cm x 2.5cm illuminated with green light-emitting diodes (led) and a red led, placed on above, below and left sides of the monitor,
respectively. Top bar flicker at 13 Hz, low bar flicker at 15 Hz and red left led flicker at 16 Hz, these frequencies were controlled precisely with an FPGA Xilinx Spartan 2E (Figure 1).

Before using the BCI, it is required to acquire an EEG base signal, where the patient is asked to concentrate on the center of the screen for 30 seconds. This stage is needed in order to normalize the powers of each of the stimuli (see Eq. 2).

EEG signals were obtained with a Grass 15LT amplifier system and digitized with a NI-DAQPad6015 (sampling frequency= 256 Hz). Analogical bandpass filter were set at 1 and 100 Hz and a notch filter at 50 Hz to eliminate powerline interference. Only one EEG channel was measured, with electrodes placed at O2 and P4, and grounded at linked A1-A2.

3. Methods

The EEG signal processing method was based on [6]. A scheme of the proposed BCI is showed in Figure 2. First, the periodogram with rectangular window of 1024 points over 1 s EEG segments was computed as:

$$P_{xx}(f) = \frac{T_s}{N} \left| \sum_{n=1}^{N} x[n]e^{-j2\pi f n T_s} \right|^2$$

where $P_{xx}(k)$ is the periodogram, $T_s$ is sampling period, $N$ is number of samples on EEG segment and $f$ is frequency. Then, normalized power $P_N$ is computed for each interest frequency as:

$$P_N(f_i) = \frac{P_{f_i}}{P_{b}f_i} + \frac{P_{2f_i}}{P_{b}2f_i} + \frac{P_{3f_i}}{P_{b}3f_i}$$

where $f_i$ is the interest frequency (13, 15 or 16 Hz); $P_b$ is the power on each $f_i$ and their second (2$f_i$) and third harmonic (3$f_i$), $P_b$ is the power on base EEG acquired previously at the experiment. In Figure 3 is presented the spectral content of an EEG segment when the subject observes the light placed above the monitor, hence an SSVEP at 13 Hz is elicited and it is observed a power increase at 13 Hz and its second harmonic at 26 Hz.

Later, the maximum $P_N$ is detected and, if this maximum is maintained for a time interval of at least 1.5 s, then that segment is classified as one of the stimulus (top, down or left).
3.1. Word selection

This setup was designed in order to allow an easy communication between the patient and the medics or relatives. In that way, if medic (or relative) takes a question to the patient, he/she can respond it easily.

The patient is presented with a series of words, separated into two sets, one at the top of the screen and one on the bottom (Figure 1). These words have been chosen so that the patient can answer some questions (“yes”, “no”, “good”, “bad”) or expressing some situations (“heat”, “pain”, “cold”, “thirst”). Thus, the subject may speak quickly, for example, during a rehabilitation session with his physician.

The patient starts by choosing the word to express, and then through a binary classification process he/she can select the chosen word, as shown in Figure 4. The patient should gaze the stimulus that corresponds to the set where the desired word is. For example, to select the word “no” the subject should gaze at the top light (Figure 4A), consequently the BCI should detect the patient intention and the upper set is subdivided into two new subsets (Figure 4B). Then, the process is repeated until the chosen word is reached (Figures 4C and 4D). At the beginning of each selection step is emitted a beep, indicating the patient can start gazing at the stimulus corresponding to the chosen bar on the screen.

![Figure 2: Scheme of proposed BCI](image)

![Figure 3. EEG Periodogram of a subject gazing at 13 Hz stimulus, the second harmonic at 26 Hz can be observed as well.](image)
Whether an erroneous detection is performed, the patient could correct it, just gazing on the red led at the left of the monitor, returning to the previous step.

Finally, once the patient gets to the desired word, it is presented on the screen and also listening on the computer speaker.

4. Results

To evaluate the proposed BCI performance, four healthy subjects (men, 29 to 33 years) were seated in front of a computer monitor and they were asked to select different words from the word set. All subjects provided written consent to participate in the experiment.

Each subject was evaluated according to accuracy in selecting the desired word, and the time spent in the process, these results are presented in Table 1. Additionally, a measure of the information transferred between the brain and the computer, the Information Transfer Rate (ITR), is showed. The ITR is calculated as [7]:

\[
ITR = (1 - P_d) \left( \log_2 N + (1 - P_e) \log_2 (1 - P_e) + P_e \log_2 \left( \frac{P_e}{N-1} \right) \right)
\]

where \( P_d \) is the rate of unknown cases (i.e., the BCI was not able to detect a SSVEP), \( P_e \) is the error rate (i.e., the BCI detects a SSVEP but it is not the stimulus the subject gazes) and \( N \) is the number of stimuli. In equation (3), the ITR is expressed in bits/trials; the maximum ITR achievable for the proposed BCI is 1.58 bits/trial. Additionally, the ITR could be expressed in bits/min considering the number of trials per minute.

The minimum number of steps to select a word is 3 steps. However, eventually it could be necessary more than 3 steps. For example, if a stimulus is not detected when subject gaze it, resulting in an undefined output; then the subject must gaze the stimulus once again after start

**Figure 4:** Selection word process for “no”. A, entire sets. B, first division of upper set. C, second division of upper set; D, final selection of “no” word. These words are in Spanish, si = yes, no = no, calor = heat, bien = good, dolor = pain, frio = cold, mal = bad, sed = thirst.

Whether an erroneous detection is performed, the patient could correct it, just gazing on the red led at the left of the monitor, returning to the previous step.

Finally, once the patient gets to the desired word, it is presented on the screen and also listening on the computer speaker.
beep signal. Another case, when a stimulus is detected erroneously, the subject can correct the wrong choice gazing at the red light on the left and the word sets is backward to previous state.

Table 1: Results on experiments

| Subjects | Average time [s] | ITR | Accuracy |
|----------|------------------|-----|----------|
|          | Total            | by trial | bits/trial | bits/min |          |
| 1        | 45.1 ±17.8       | 9.465 | 1.185     | 7.625    | 100%     |
| 2        | 26.3±9.7         | 9.346 | 1.25      | 9.56     | 75%      |
| 3        | 17.3±0.5         | 5.73  | 1.58      | 16.616   | 100%     |
| 4        | 17±0.8           | 5.667 | 1.58      | 16.82    | 100%     |
| Average  | 26.42            | 8.159 | 1.185     | 12.121   | 94%      |

5. Discussion

In this work was implemented a BCI that allows a disabled person respond quickly and concisely to the questions that might make his caregivers. This is accomplished through a robust system that gets on average 94% accuracy in reaching the desired word.

In this preliminary stage, the BCI was tested in four healthy subjects. All subjects always achieved the desired word, except subject 2. Subjects 3 and 4 had better performances as they reached the desired word within the shortest possible time (17 s) and the maximum possible ITR for the BCI is reached, i.e. 1.58 bits/trial.

In [8] a speller was implemented through a decision tree and an undo command to correct any errors. This BCI, was tested in eight healthy subjects with an accuracy rating of 92.25% and 37.62 bits/min, which translates into an average speed of 5.51 letters per minute. In this work was attained a lower ITR (up to 16 bits/min), but it is possible to select a whole word in 26.42 s.

In [9] a spatial filter was used for the detection of SSVEP with an average ITR of 27 bits/min, however this algorithm is more complex and with higher computational cost than proposed method on this paper.

Generally, in related works the stimulation flickering was performed on the same screen. In [10] was evaluated various parameters using the screen (such as frequency range, resolution, stability, etc.) and it was founded that cannot be render frequencies above 30 Hz (or half the monitor refresh rate). In this work, using stimulation with leds, it is possible to achieve higher frequencies than 30 Hz. These high-frequency SSVEP range has the advantage of a great decrease of visual fatigue caused by flickering, making the SSVEP-based BCI a more comfortable system [11].

Although, the word set is limited, it was designed in order to answer a wide range of questions, where the patient is able to respond fast and accurate to doctor or relative questions.

6. Conclusions

In this work, was implemented a SSVEP-based BCI that could allow a person to communicate fast and without much effort, i.e., it is possible to select a word in an average time of 26 s with accuracy in word selection on average of 92%.

This BCI approach is intended to be used in the first stages on rehabilitation or even in first moments of some diseases (such as stroke), when the person is desirous to communicate and the physician need to talk with the patient. Eventually, depending on the patient recuperation, a more sophisticated BCI could be used or no use a BCI.

As future perspectives, it is planned to extend the set of word and to develop a faster method to select words on the screen and moreover, to test the system in disabled people.

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