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Structuring Elements for the P300 Event-related Potential Detection

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Introduction

Feature extraction from electro-encephalographic (EEG) recordings for further use in brain-computer interfaces was a topic that gathered a lot of attention in recent years, due to the large range of possibilities to choose among features and the diversity of methods to extract them. Until now, there is no consensus between researchers over which method and feature proves to be the best suited, every study being focused on a specific topic that solves a practical problem that was faced during the development of a certain brain-computer interface.

The external events, such as visual and auditory stimuli generate transient responses in the EEG signal, which are generally known as event-related potentials (ERP). There are many event-related potentials and each one may be used, in principle, as a feature, as long as its connection with the stimulus is clearly evidenced.

The P300 event-related potential as a feature of the EEG

In this paper we investigate the possibility of using the P300 event-related potential as a feature that characterizes the response of a human subject to a stimulus generated by the computer used in a brain-computer interface.

From the psychological point of view, the P300 event-related potentials maintain the functioning of the brain, in the same way dynamic RAMs use their refresh signals [1].

There are two main features that were studied concerning P300 as an impulse: its amplitude and its duration. These attributes are correlated with biological determinants grouped in three types of factors: natural, induced and physical [2]. As a result, the amplitude of the P300 impulse is influenced by food, season and the time interval of activity of the subject (natural factors), fatigue, medication (induced factors) and age, IQ, personality and genetic factors (physical ones). The duration is influenced by body temperature and heart rate (natural factors), physical exercises, fatigue, medication, caffeine, nicotine and alcohol (induced factors) and age, IQ and factors (physical ones).

The biological determinants outlined in [2] show that detecting the P300 event-related potential is not an easy task when involving only amplitude and duration, their variability being an important challenge that needs to be surpassed. Nevertheless, a widespread agreement lies in the fact that the P300 event-related potential is generated no sooner than 300 milliseconds after an event, priorly known to the subject, with low rate of probability of occurrence (a Bernoulli-type event), has taken place.

Our paper suggests another approach, based on the shape of the impulse, which involves mathematical morphology as a basic tool for detecting the occurrence of the P300 event-related potential.

In what follows, we shall briefly review the theoretical background for the basic morphological operators used henceforth, the criteria employed to choose between the possible structuring elements, the detection thresholds and some results on real data sets. In the end we present our concluding remarks and a few possible future research topics.

Morphological operators

The morphological operators were introduced as tools of mathematical morphology in [3–5] and as set or function processing ones in [6, 7].

There are two basic operators that are used in mathematical morphology: erosion and dilation.

To be specific, let $f : N \rightarrow R$ and $se : N \rightarrow R$ be two discrete functions defined on N (the set of positive integers) with values in R (the set of real numbers). The function *se* is named structuring element and the following definitions are adapted for the case of positive integers. Consequently, the erosion with the structuring element *se* is defined as

$$(f \circ se)(m) = \min_{n \in N}(f(m+n) - se(n)), \quad m \in N\ . \qquad (1)$$

The dilation with the same structuring element *se* is given by

$$(f \bullet se)(m) = \max_{n \in N}(f(m+n) + se(n)), \quad m \in N\ . \qquad (2)$$

In a real case, the sets involved above are finite sets. It is important to notice the fact that the structuring element has a crucial role in the final result of the operation and in spite of the same notation used above; the structuring element may differ when erosion and dilation are applied successively. In fact, there are two important cases when this happens, namely when defining the so called opening and closing operators.

To obtain the opening operator, erosion is applied first, followed by dilation

$$open(f,se) = (f \circ se) \bullet se\ . \qquad (3)$$

For closing, the order is reversed

$$close(f,se) = (f \bullet se) \circ se\ . \qquad (4)$$

It is worth noticing the fact that the domain of *se* must be smaller than the one of the function *f*.

From the above definitions one can easily see the fact that the *f* function is “smoothed” from below when opening is applied and from above when closing is used. To express it in a different way, opening cuts the peaks, while closing fills the valleys. This property may be used to extract the P300 event-related potential from the EEG recordings based on its morphological properties.

The main problems consist in finding the adequate structuring elements that are able to perform opening and closing, their length, the connection of the statistical properties of the signal to the parameters that characterize the structural elements and the definition of a criterion that is able to show the measure of confidence in the P300 event-related potential detection.

The data set

The signals that were used in this study were acquired by means of a 10-20 system of electrodes placed on a human scalp. A Donchin paradigm, [8], was used to collect the data: the user was presented with a 6 by 6 matrix of characters and was asked to focus his attention on the characters in a word; each character of the word appeared in their initial succession, but randomly. The responses evoked by these infrequent stimuli are different from those elicited by the stimuli that did not contain the desired character, and they are defined as P300 event-related potential responses. So a P300 pulse is generated every time the subject of the study encounters a change in the illumination of a row or column that has a letter on which, according to the chosen word, the attention of the subject is focused on at that moment.

Not all the electrodes in a 10-20 system are of interest when dealing with P300 potential; our study was focused on signals generated by Cz, CP1, CP2, C1-C6 electrodes, and they are part of the data set II, as defined in [9].

The great variability of the P300 impulse led us to the decision to obtain from the initial raw data averaged ones. Fig. 1 presents the averaged signal that was obtained from the Cz electrode when the P300 event-related potentials were generated.

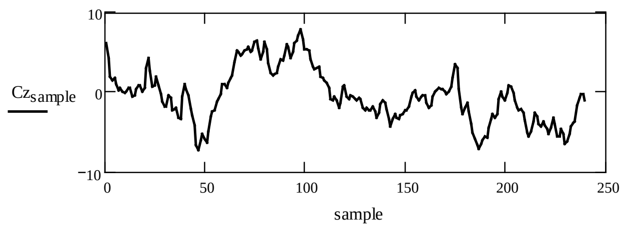

Fig. 1. The averaged signal for the Cz electrode with the P300 event-related potential

In this way, we were able to find the adequate values of the parameters that characterize the structuring elements that are valid for the detection of every instance of P300. Taking into account the sampling frequency, the interest zone for the P300 impulse lays between samples 60 and 100, as seen in the Fig. above.

The signal for the same electrode, averaged in the case of the missing P300 is the one in Fig. 2.

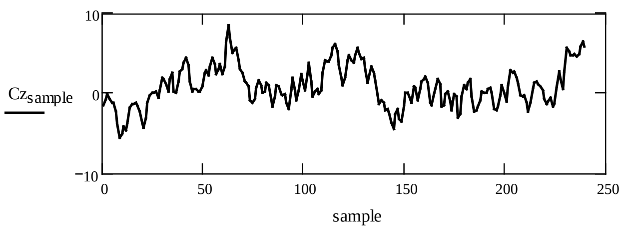

Fig. 2. The averaged signal for the Cz electrode without the P300 event-related potential

The structuring elements

Probably the most used structuring element when dealing with morphological filters is the circle. It was used from the beginning [4, 5], but also in recent studies [10]. The main problem in using it, in fact as for any of the other structuring elements, is the way we link the properties of the signal, especially the statistical ones, with the parameters that characterize the shape (e.g. the radius). If we consider the circle as a particular form of ellipse than we may be able to fit the shape to the signal better, since there are two parameters that can be adjusted, the length of the two axes of the ellipse. Nevertheless, the circle option is still possible if we consider both axes of the ellipse equal to each other.

Fig. 3 presents the signal (continuous line), the result of opening of the signal with an ellipse with one axis equal to the maximum value of the signal and the other with the standard deviation of the signal (dotted line) and the opening of the signal with a circle with unit radius (dashed line).

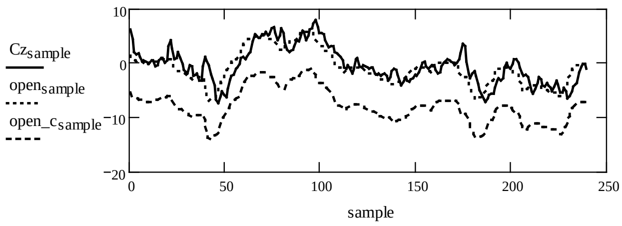

Fig. 3. The averaged signal for the Cz electrode bearing the P300 event-related potential (continuous line), its opening with an ellipse (dotted line) and opening with a circle (dashed line)

The following functions were considered as structuring elements:

$$se(n) = |b_y| \cdot \sqrt{1 - \frac{n^2}{a_x^2}}\,, \tag{5}$$

$$se(n) = -a \cdot n^2 + |b|\,, \tag{6}$$

$$se(n) = a \cdot \left(1 - e^{-\alpha n}\right). \tag{7}$$

Our study was also focused on finding the possible links between the signal and the parameters of the above functions, so that only details were left to be removed from the signal after applying the opening and closing operators.

First of all, the best results in detecting the P300 event-related potential were obtained for the last structuring element, given by (7), with a equal to the mean value of the signal and α=0.01.

The other structuring elements were linked with the signal statistical properties as follows: the ellipse in formula (5) had the b_y parameter equal to the maximum value of the signal and a_x to the standard deviation. In formula (6) the parameter a of the function is equal to the standard deviation while b was chosen to be equal to the mean value of the signal.

Another point of interest is how to choose the number of elements of the set of definition for the structuring element. If this number is too large, then the nonlinear "filtering" properties of the morphological operators are too evidenced; a smaller number of points, between 2.5% and 5% of the total number of points of the signal, proved to be satisfactory for a clear detection of P300.

Due to the variability of the EEG signals, it may be necessary to emphasize one of the two basic operations, opening or closing. To do so we suggest the following aggregate between the two operators

$$agg(m) = \lambda \cdot open(m) + (1 - \lambda) \cdot close(m)\,, \tag{8}$$

where $\lambda \in [0, 1]$ is a shape parameter that has the role of emphasizing one or the other operator.

This may lead to a better adjustment of the function, so the user is able to fine-tune the detection process in the desired way.

Let us consider the averaged signal from the C1 electrode in Fig. 4 (dotted line).

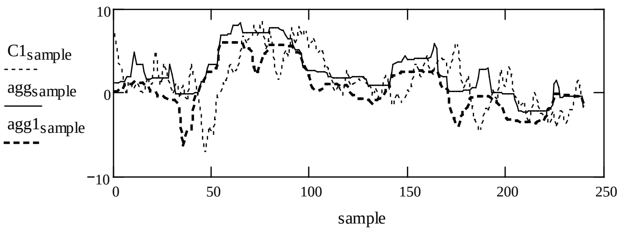

Fig. 4. The averaged signal for the C1 electrode (the dotted line) and the aggregate signal for λ=0.1 (the continuous line) and for λ=0.9 (the dashed line)

The structural element used was in both cases (opening and closing) the one given by equation (7) with the above mentioned parameters. The length of the structuring element was 5% of the original signal. It may be clearly seen in Fig. 4 that the behavior of the operators working in tandem may be changed by a proper choice of the shape parameter. To accomplish our task, the detection of the P300 event-related potential, smaller values of the shape parameter (λ<0.1) led to a better highlighting of the impulse, i.e. the closing operation was greatly emphasized. This makes sense since the impulse is a positive one.

The detection criterion

When dealing with aggregate signals of the above type, one must be sure when to count a positive detection of the P300 event-related potential. That is why we suggest using the mean value of the aggregate signal as a detection threshold for the P300 impulse.

It's worth noticing that the mean value of the initial signal may be slightly different from the one of the processed signal, since λ, the shape parameter, is not always 0.5. Even so, the mean value is still a strong candidate for the detection threshold as long as it is computed for the aggregate signal, as shown in Fig. 5.

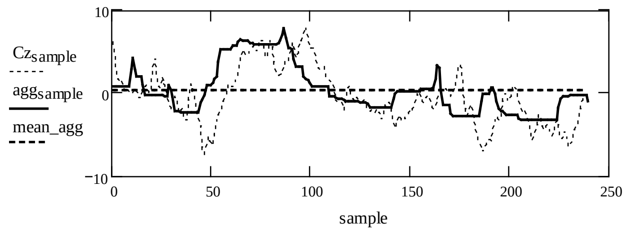

Fig. 5. The averaged signal for the Cz electrode (the dotted line) and the aggregate signal for λ=0.1 (the continuous line) and mean value of the aggregate signal (the dashed line)

From the above Fig. it is obvious that the best criterion to detect the P300 potential is the one that states the fact that after 300 milliseconds from the stimulus, the aggregate signal is greater than its mean value for at least another 300 milliseconds. Translated into samples, this means that the signal is greater than its mean value for samples between 50 and 100.

There are cases when this criterion is still valid but it is not so evident, like in Fig. 6, where for the C8 electrode a clear descending tendency changes somewhat the area that is greater than the mean value of the aggregate signal.

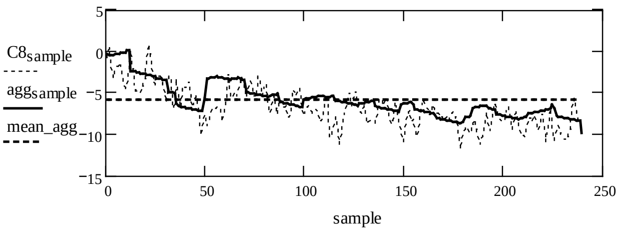

Fig. 6. The averaged signal for the C8 electrode (the dotted line), the aggregate signal for λ=0.1 (the continuous line) and mean value of the aggregate signal (the dashed line)

This observation led us to the conclusion that a better quantitative measure of the area above the mean value could be defined to add more accuracy to the detection process, but this is beyond the purpose of this paper.

Conclusions

The morphological operators may be used to detect the P300 event-related potential based only on its shape. The structural elements used in the process must be linked by the statistical properties of the signal and to evidence it better it is necessary to use an aggregate signal obtained from a mixed process of closing and opening. The threshold used in the detection procedure was the mean value of the aggregate signal. Further work will be needed to develop a quantitative criterion to decide the existence of the P300, based on the area that is above the mean value line, even if there are cases when some parts of the aggregate signal are below this value.

Acknowledgement

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The paper presents a method to detect the P300 event-related potential based on its shape. The main tools for this purpose are two morphological operators, the closing and the opening, involving dedicated structuring elements. Several structuring elements were linked to the statistical properties of the signal by means of their parameters and a new aggregate operator was developed. In the end a criterion to detect the presence of the P300 event-related potential was presented. Ill. 6, bibl. 10 (in English; abstracts in English and Lithuanian).

R. Ursulean, A. M. Lazăr, M. Istrate. P300 potencialiai susijusių įvykių nustatymas taikant struktūrizuotus elementus // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 9(105). – P. 85–88.

Pateikiamas metodas skirtas aptikti P300 potencialiai susijusiems įvykiams, paremtiems forma. Pagrindinės priemonės yra dvi: morfologiniai operatoriai (uždarymo ir atidarymo), siejantys struktūrizuotus elementus. Naujas operatorius gali būti sukurtas turint keletą struktūrizuotų elementų su signalo statistinėmis savybėmis. Il. 6, bibl. 10 (anglų kalba; santraukos anglų ir lietuvių k.).