Analysis of the brain activity spatio-temporal patterns for development of brain-computer interfaces

Author: Michał Piela

Summary

The thesis concerns development of methods for the analysis of the brain activity spatio-temporal patterns aimed at the improvement of brain-computer interfaces (BCI). BCI systems enable communication between a human and a computer by means of brain waves, recorded by EEG equipment, without using muscles, voice or body expressions. The BCI system involved in this thesis is based on a detection of the evoked potentials (EP) induced in the user's brain by the presentation of the visual stimuli. Such BCI system's main goal is to detect the presence or absence of EP component in the response to the stimuli. A BCI user interface typically contains a certain number of objects (items, letters etc.) on the screen which are blinking in a random way, one after another. During this time, a user is focused on a one, selected object, so called target. A target flash should, due to the mentioned user's intentional focus on it, and the element of surprise, trigger a higher brain response than the flashes of the other unobserved objects, called as nontargets. However, the amplitude of a brain response to a single flash (regardless of a type of the trigger which induced this response: target or nontarget) is very low and usually hidden in the waves associated with a routine activity of the brain. In effect the BCI experiments are designed so that the flash of each object is repeated multiple times and by thus more brain responses are stored. By averaging these repeated responses, separately for each object, one can more accurately determine which object generated the highest averaged response. Such an object can by thus be detected as a target object (the one observed by the user). This thesis research concerns the filtering and detection of such visual evoked potentials. Improving the efficiency of filtering, leading to an increase in the accuracy of the classification of these potentials, can contribute to the development of the existing BCI systems.

The aim of the thesis was to apply spatio-temporal filtering (STF) to EEG data processing for brain responses classification, and by the proper adjustment of the method to achieve a substantial improvement of the classification accuracy, allowing for more successful operation of the BCI systems involved. The STF method, which was first proposed for detection of low amplitude fetal QRS complexes, appeared to be inefficient in processing and classification of the EEG signals. It was the consequence of immensely low signal to noise ratio, typical for these signals. To overcome this problem, the STF method should have been modified, so that it could be more immune to noise. The main problem that must be overcome in the learning phase of classifiers used in BCI systems is the large size of the feature vector describing a single brain response to a visual stimulus and a small number of training data, i.e. such registered responses. The second important factor hindering the learning phase is the occurrence of high amplitude artifacts in the EEG signal. However, during classification of brain responses, a major complication stems from a possibility of their different delays (so-called latencies) in relation to the stimuli onsets, which may result from the different speed of the brain's response to individual stimuli.

The research performed as part of this dissertation resulted in development of a few modifications of spatio-temporal filtering, which to some extent allowed to overcome the previously described difficulties. The problem related to a small number of learning data was solved by the appropriate use of the entire recorded parts of EEG signals (not only those related to the brain's responses to the respective stimuli). In order to remove high-amplitude artifacts, two alternative methods of their detection and suppression were developed (the first one based on discrete cosine

transform and the second based on independent component analysis). Another modification of the learning phase of the STF filter involved averaging of the feature vectors describing the brain's responses to visual stimuli. Difficulties resulting from various delays of the brain's response to these stimuli have been reduced by modifying the rules for interpreting the filtering results. The main assumption in this case was a need to analyze the STF output signals not only for a specific expected position, but in a wider range, in order to detect the maximum response of the filter to a given stimulus.

Verification of the methods described in the thesis, performed on two databases, confirmed the efficiency of the proposed solutions. The results obtained for the first database („Item selection”) exceeded those achieved by most of the reference methods with just a slight loss to the winning algorithm. On the other hand, for the second database, the results obtained by the most effective solutions described in this thesis were much better than those obtained by the reference methods.

Taking into consideration the verification results of the developed solutions and the obtained high accuracy of visual evoked potentials classification, it seems justified to conclude that the objectives of the thesis have been achieved. The proposed solutions may contribute to the development and improvement of the efficiency of currently used brain-computer interfaces.