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A data partitioning method for increasing ensemble diversity of an eSVM-based P300 speller

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ABSTRACT

A P300 speller is a device for typing words by analysing the electroencephalogram (EEG) caused by visual stimuli. Among classifying methods used for the P300 speller, the ensemble of support vector machines (eSVM) is well known for achieving considerable classification accuracy. The eSVM is composed of linear support vector machines trained by each small part of the divided training data. To obtain an ensemble model with good accuracy, it is generally important that each classifier be as accurate and diverse as possible; diverse classifiers have different errors on a dataset. However, the conventional eSVM considers only an accuracy viewpoint of an individual classifier by clustering the homogeneous training data with similar noisy components. With such a viewpoint of diversity, we propose a dataset manipulation method to divide a training dataset into several groups with different characteristics for training each classifier. We reveal that the distance between a letter on which a subject is concentrating, and an intensified line on a visual keyboard, can generate EEG signals with different characteristics in a P300 speller. Based on this property, we partition the training data into groups with the same distance. If each individual SVM is trained using each of these groups, the trained classifiers have the increased diversity. The experimental results of a P300 speller show that the proposed eSVM with higher diversity improves the letter typing speed of the P300 speller. Specifically, the proposed method shows an average of 70% accuracy (verbal communication with the Language Support Program is possible at that level) by repeating the dataset for a single letter only four times.

1. Introduction

A P300 speller is a popular brain computer interface (BCI) system, which enables people to spell a text on a computer through visual stimulus [1]. A P300 speller uses a P300 component, which has a positive peak at nearly 300 ms after stimulus, because the P300 component reflects a higher response by stimulation than other components. When the P300 wave is detected for a letter, the repeatedly obtained electroencephalogram (EEG) signals are averaged to increase the signal-to-noise ratio (SNR) [2]. However, the measured EEG signals are mixed with other bio-signals such as electrooculography and electromyography. Because these unexpected signals cannot be approximated by a zero-mean Gaussian random process, it is difficult to detect P300 signals by simply averaging EEG signals. To detect P300 signals efficiently, several classification methods, such as an artificial neural network, linear discriminant analysis, and support vector machine (SVM), have been introduced in a P300 speller [3–5].

To encourage further development of signal processing and classification methods for the BCI, BCI Competition III [6] was held and P300 speller data were included in the competition. The competitors proposed various algorithms for a P300 speller to estimate correct letters using training and test data, without true letter information. Among the proposed algorithms, the algorithm using an ensemble of SVMs (eSVM) exhibited the best performance in terms of estimation accuracy [7]. It was shown that the algorithm using eSVM had better performance than that using a single SVM where there were less iterations of training data [5]. Because this algorithm is a bagging method that is one of the ensemble of classifiers, it could reduce the influence of signal variability by averaging classifier outputs [5]. For individual SVM accuracy improvement, the conventional eSVM considered that the dataset, an input to a single classifier, has homogeneity, which signifies that the dataset has similar noisy components.

Since then, there have been several efforts for P300 speller performance improvement using an ensemble method, in terms of training time and accuracy. An ensemble method takes significant

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training time owing to several classifiers. In order to overcome this, an attempt was made to employ wavelets and an ensemble of Fisher's linear discriminant (FLD) [8]. Even though the algorithm could reduce the training time by using FLD with a shorter computation time than SVM, the classification accuracy decreased. Following that attempt, Perseh and Kiamini [9] achieved the reduction of training time by utilising event related potential (ERP) signals and FLD; however, this method also resulted in reduced classification accuracy. The majority of the efforts to decrease training time have suffered from lowered classification accuracy. El Dabbagh et al., in a study using an ensemble method to improve classification accuracy, proposed an ensemble of weighted SVMs and eSVM employing a new clustering of training datasets [10]. However, these methods achieved minor improvements.

Another indicator of the performance of a P300 speller is the typing speed, which is the speed at which one letter is entered. The typing speed is used as an important measure to assess the feasibility of a real BCI system because it affects user convenience. The speed is affected by the number of repetitive data, which are repetitively obtained signals increasing the SNR of the signal in the P300 speller. Decreasing the number of repetitions increases the typing speed, but may lower the accuracy. However, because errors within 30% of all input letters of a P300 speller can be corrected through the Language Support Program, keeping the classification accuracy above 70% and reducing the number of repetitions can increase the typing speed and ensure the accuracy of the P300 speller. In terms of this typing speed, the subsequent studies on the eSVM [8–10] mentioned above have approximately the same typing speed as the conventional eSVM.

This paper aims to enhance this typing speed by modifying the algorithm of the conventional eSVM. Reducing the number of repeatedly obtained data enhances the typing speed; however, it may also increase signal variability. Nevertheless, the problem of increased signal variability can be reduced by improving the ensemble method. The performance of an ensemble method is known to be affected by the accuracy of an individual classifier and diversity within the ensemble [11]. Diversity means that when the same data is entered into classifiers, the classifiers produce different outputs. If the outputs of the classifiers are uncorrelated, then, high ensemble diversity exists, and the ensemble will usually achieve error reduction over the individual classifiers. In the ensemble method used in the present P300 spellers, there is no performance improvement research that considers diversity.

In this respect, this paper proposes an improved P300 speller based on eSVM using the simple data manipulation of grouping the input dataset on each classifier. Because the obtained EEG signals can have different characteristics depending on the distance between the target letter and given stimulus, we group the input data according to the distance. The individual classifiers are trained by different groups of datasets. Because the difference in the groups can reduce the correlation between the separating hyperplanes of the trained classifiers, the diversity of the ensemble can be increased. Therefore, the proposed method may increase the classification accuracy of the ensemble method owing to the increased diversity. We verified the accuracy of the proposed method by using the open source of the dataset II of BCI competition III. The competition has provided one training and one test datasets for each of the two different subjects. The EEG signal was recorded from 64 electrode channels and more details about the experimental setup are in [6].

The rest of this paper is organised as follows: In Section 2, a P300 speller is described and the eSVM is described in Section 3. A new P300 speller using dataset manipulation for ensemble diversity is proposed in Section 4. Through the experimental results, in Section 5, we compare the accuracy of the proposed P300 speller with that of the conventional P300 speller. This paper is finally concluded in Section 6.

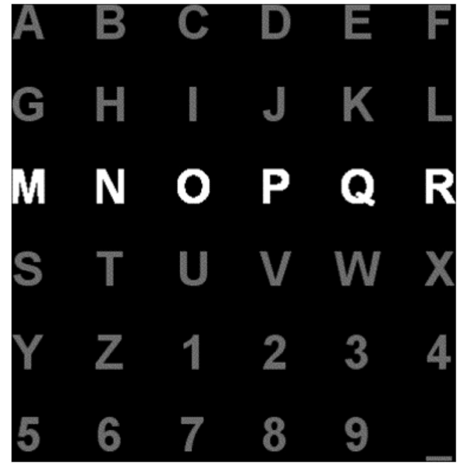

Fig. 1. A 6×6 user display in a P300 speller.

2. A P300 speller

2.1. Visual stimulus for a P300 speller

ERPs are a measured brain response caused by specific stimulus. The recorded ERPs are very small voltages caused by the background brain activity together with other bio-signals. This signifies that ERPs are not easily detected in the EEG recording of a single trial. Thus, the EEG signals obtained from many trials are averaged to confirm a distinct ERP response to a stimulus. The P300 wave is an ERP component and shows a positive peak at nearby 300 ms after a stimulus. A P300 speller uses a P300 component, which reflects a higher stimulus response than other components.

A P300 speller presents target letters by analysing P300 waves from the EEG signals obtained when visual stimuli are provided for a subject using a display. To secure the objectivity of tested BCI data, we used dataset II from BCI Competition III [6]. The dataset was obtained using a paradigm described by Farwell and Donchin [1], in which a matrix of 6×6 cells is used to represent 36 letters, as shown in Fig. 1. For a single-target letter, each of the six rows and six columns is intensified and the intensifications are presented in a random sequence. A subject focuses attention on one of the 36 cells of the matrix and then, a P300 wave is evoked in response to the intensification of a row or column containing the target letter. In order to enhance the reliability of the speller, a set of 12 intensifications is repeated 15 times for each letter.

2.2. EEG data analysis for a P300 speller

A P300 speller displays one of the 36 letters by analysing the EEG caused by the visual stimuli. However, in terms of signal analysis, it deals with a problem of separating two EEG patterns according to the existence of the P300 component. As mentioned above, it provides 12 stimuli for each letter. Only two stimuli out of the 12 produce EEGs related to the desired target letter, and have a P300 component. The EEGs obtained from the remaining 10 stimuli are not related to the desired target letter and do not have a P300 component. This one set is repeated 15 times, and thus, 15×12 data are used to find one target letter by combining individual results after pattern recognition. A P300 speller uses machine learning to recognise and separate the two types of EEG patterns.

Machine learning is a method of automatically creating a system model to predict new data by recognising a pattern of several