Simple Convolutional Neural Network for Left-Right Hands Motor Imagery EEG Signals Classification

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ABSTRACT

This article proposes a classification method of two-class motor imagery electroencephalogram (EEG) signals based on convolutional neural network (CNN), in which EEG signals from C3, C4 and Cz electrodes of publicly available BCI competition IV dataset 2b were used to test the performance of the CNN. The authors investigate two similar CNNs: a single-input CNN with a form of 2-dimensional input from short time Fourier transform (STFT) combining time, frequency and location information, and a multiple-input CNN with 3-dimensional input which processes the electrodes as an independent dimension. Fisher discriminant analysis-type F-score based on band pass (BP) feature and power spectra density (PSD) feature are employed respectively to select the subject-optimal frequency bands. In the experiments, typical frequency bands related to motor imagery EEG signals, subject-optimal frequency bands and extension frequency bands are employed respectively as the frequency range of the input image of CNN. The better classification performance of extension frequency bands show that CNN can extract optimal feature from frequency information automatically. The classification result also demonstrates that the proposed approach is more competitive in prediction of left/right hand motor imagery task compared with other state-of-art approaches.

KEYWORDS

Brain Computer Interface, Classification, Convolutional Neural Network, Electroencephalogram, Fisher Discriminant Analysis-Type F-Score, Motor Imagery, Optimal Frequency Band, Short Time Fourier Transform

1. INTRODUCTION

A brain-computer interface (BCI) is a hardware and software system that can communicate with computer or external devices through brain activity (Nicolas-Alonso and Gomez-Gil, 2012). BCI system can provide a new human computer interaction method which does not depend on the traditional peripheral nervous system and muscle tissue such as a mental typewriter presented by Berlin BCI (Blankertz et al., 2006) and an approach based on recognition of sign language from imagination (Al Qattan and Sepulveda, 2017). BCI is also a promising technology for the communication of locked-in state (CLIS) patients (Nicolas-Alonso and Gomez-Gil, 2012; Hinterberger et al., 2003) as well as the interaction with videogames or virtual environments (Lécuyer et al., 2008). In recent years, BCI has
also made significant progress in speech imagery analysis (Chengaiyan and Anandhan, 2015) and attention detection (Subramanian et al., 2017).

A key phenomenon observed across different recording modalities is that the neurophysiological rhythmic activities, mostly in alpha (7-13 Hz), mu (8-12 Hz), beta (14-30 Hz) and gamma frequency bands (>30 Hz), recorded over the sensorimotor cortex are modulated by actual movement, motor intention, or motor imagery. Such rhythmic brain activities measured by EEG or other recording modalities over the sensorimotor cortex are collectively referred to as the sensorimotor rhythms (SMRs) (Yuan and He, 2014). Motor imagery (MI) EEG signals is a kind of original EEG signals containing SMRs. MI-EEG signals one of the most popular EEG signals used in non-invasive BCI studies to serve as control signals. Different MI tasks can cause different oscillatory activities observed in the sensorimotor cortex of the brain in the form of event-related desynchronization (ERD) or event-related synchronization (ERS) (Pfurtscheller and Da Silva, 1999).

Nevertheless, compared with such traditional interaction modes as keyboard and mouse, the precision and reliability of BCI system are still insufficient since the performance varies greatly across or even within the subjects (Ahn and Jun, 2015). EEG signals are often distorted by such artifacts as electromyography (EMG) or electrooculography (EOG) (Nicolas-Alonso and Gomez-Gil, 2012). Moreover, in most of the cases, EEG performance is a typical non-stationary process. Therefore, it is still a significant challenge to decode mental activities from EEG signals accurately.

In recent years, with the increase of the size of data, deep learning algorithm is known to provide better classification performance in such fields as shape recognition and speech recognition. In the study on BCI, (An et al., 2018) construct a deep belief net (DBN) for MI EEG signals classification and their results is better than those from SVM. (Yang et al., 2015) also employ convolutional neural networks (CNN) to classify the augmented common spatial pattern (ACSP) features of MI-EEG signals. In recent study, (Tabar and Halici, 2016) investigate convolutional neural networks and stacked autoencoders (SAE) which have better classification performance compared with state-of-art approaches for left/right hand MI-EEG signals classification.

Inspired by the success of CNN-SAE proposed by (Tabar and Halici, 2016), in order to reduce the parameters of neural network and improve the performance, we extend their work of CNN on the classification of motor imagery EEG signals. The proposed approach is analyzed and evaluated by using BCI Competition IV dataset 2b (Leeb et al., 2008).

In this paper, the processing method of input data of CNN combining time, frequency and location information is introduced. First, the original signals obtained from C3, Cz and C4 electrodes are preprocessed to extract useful information of MI-EEG signals. Then Short Time Fourier Transform (STFT) is employed to convert the preprocessed data from each electrode to 2-dimensional feature matrix. The data of feature matrix of related frequency bands (i.e. mu band and beta band) from each electrode is extracted and combined to one matrix which consists of the input data of CNN.

In our study, 1-dimensional convolutional neural network is constructed and trained by the input images to learn the activation pattern. Since CNN only contains one convolutional layer and one max-pooling layer, this significantly reduces the parameters of network compared with CNN-SAE and the optimal neural network can be easily developed to improve the classification performance. To improve the performance of CNN, typical mu band and beta band related to MI task, optimal frequency bands selected by fisher discriminant analysis-type F-score based on band pass (BP) feature and power spectra density (PSD) feature, and Extension Frequency Bands are employed on BCI Competition IV dataset 2b to select the optimal frequency band of input data of CNN.

2. METHOD

Source imaging studies of SMRs have revealed that movement or motor imagery of different body parts were associated with decrease in SMR from regions along the primary sensorimotor cortex corresponding to different body parts, known as the Homunculus (Yuan and He, 2014). Usually, the
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