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# Optimal Spatio-Spectral Variable Size Subbands Filter For Motor Imagery Brain Computer Interface

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**Abstract**

Common spatial pattern (CSP) is a commonly used feature extraction technique for motor imagery brain computer interface. CSP provides poor performance when features are extracted from unfiltered or irrelevant frequency band filtered data. In order to overcome this problem, Subband CSP (SBCSP) and Filter Bank CSP (FBCSP) have been proposed in literature to extract features from several fixed size subbands. However, both SBCSP and FBCSP require manually fixing the size of subbands to obtain higher performance. In this paper, we propose a method that obtains features from many variable size subbands within a given frequency band using CSP. Further, Euclidean distance measure is used to obtain the relevant features. The efficacy of the proposed method is evaluated in terms of classification error on BCI Competition III dataset IVa and BCI competition IV dataset Ia. Experimental results demonstrate that the proposed method achieves better performance in comparison to CSP, SBCSP and FBCSP.

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## 1. Introduction

A Brain computer interface (BCI) interprets neuronal activity to derive user commands and thus creates a direct communication pathway between a brain and a device without involving the brains conventional output pathways such as muscles or peripheral nerves[1]. The electrical signals occurring in the brain due to neuronal activity carry information for the purpose of communication with a computing device. It has been of profound interest to many researchers due to its extensive applicability in medical and industrial field. The main objective of a BCI is to help a person with intense motor disabilities to control devices such as computers, speech synthesizers, assistive appliances and neural prostheses[2] which can provide fast information communication. For the analysis of brain signals, machine learning approaches and signal processing techniques have been considered of extreme importance. EEG brain signals are used widely for analysis of brain states due to their low measurement cost, high temporal resolution and non-invasive nature. An increased attention is observed for an EEG based motor-imagery paradigm which involves thinking or imagination of movement of a specific body part. Imagination or execution of limb movement induces variations in rhythmic activity recorded over Sensorimotor Cortex[7] called Sensorimotor Rhythms (SMRs), which can be detected

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on the scalp by EEG. The amplitude of SMRs decreases during motor execution or imaginary. This decrease in rhythmic activity is called as Event-Related Desynchronization (ERD) and increase in the rhythmic activity immediately after the movement is called as Event-Related Synchronization (ERS)[1,3,4,5].

Raw EEG signals suffer from weak spatial resolution due to volume conduction[1,6]. This becomes a problem when the relevant signals are weak while in the same frequency band, other irrelevant sources (artifacts) produce strong signals. For single trial EEG analysis, system is calibrated to the specific characteristics of each user by calculating subject specific spatial filters. These spatial filters are designed in a way that the variances of the out-coming signals carry the most discriminating information.

As a data-driven technique, CSP[3] technique is one of highly successful spatial technique which helps in estimating spatial filters to analyze multichannel data in motor imagery BCI. The goal of this technique is to find the spatial filters from a linear combination of a multichannel signal which maximizes variance for one class and minimizes variance for the second class simultaneously[3,6,7]. The spatial filters obtained are applied to relevant frequency bands ($\alpha$ and $\beta$ bands) data to obtain features. These discriminative frequency bands are subject-specific in nature. If CSP spatial filter is applied to an EEG signal filtered using an irrelevant frequency band, the extracted features will give poor performance. Hence, frequency band selection is an important issue to be handled. Exhaustive search and manual tweaking can help in learning the best bands, but being time consuming, are not suggested. Also, there is no standardized technique for selecting the best frequency bands. The major problem in CSP is tuning of BCI device for every subject as the rhythmic patterns of $\alpha$ and $\beta$ rhythms varies from subject to subject. The presence of artifacts and the non-stationary nature of an EEG trial data may further deteriorate the performance of CSP[8,9,10]. More recently research has been focused on finding spatial patterns from a filter bank of non-overlapping fixed sized subbands. Subband CSP (SBCSP)[11] has been used to analyze motor imagery data using different fixed sized subbands. Filter bank CSP (FBCSP)[12] allows analysis of CSP technique by applying it on different frequency bands filtered EEG based on maximal mutual information criterion.

However, both SBCSP and FBCSP require manually fixing the size of subbands to obtain higher performance. Also, these methods do not explore variable size subbands present in a given frequency band, which may further improve the performance of motor imagery based BCI. In order to obtain relevant subbands, we propose a method that obtains features from many variable size subbands with in a given frequency band using CSP. The proposed method involves the following five phases: (i) generation of variable sized frequency subbands and bandpass filtering of raw EEG signals using these subbands, (ii) Features are obtained from each of these subbands filtered data using CSP, (c) CSP features from each subband are then evaluated to obtain bandscore using linear discriminant analysis, (d) Obtained band scores are ranked using Euclidean distance measure, (e) learning a decision model on obtained higher ranked features.

The performance of the proposed method is evaluated on publicly available BCI Competition III dataset 4a and BCI competition IV dataset Ia in terms of classification error and compared with existing methods. Experimental results demonstrate that the proposed method achieves better performance in comparison to CSP, SBCSP and FBCSP. The major contributions of this paper include (a) to provide with an algorithm that can automatically generate all the variable size subbands present within a given frequency band (b) to provide a more robust feature selection method to remove irrelevant frequency bands (c) to analyze the behavior of the proposed method of feature extraction using linear (LDA) as well as non-linear (SVM) classifier (d) to compare the performance of the proposed method on the publically available datasets.

Rest of the paper is organized as follows. Section 2 discusses existing spatial filters based feature extraction techniques. The detailed description of the proposed scheme of feature extraction is given in Section 3. Section 4 includes experimental results. Finally, Section 5 concludes the article and provides some future research directions.

## 2. Related Works

### *2.1. Common Spatial Patterns (CSP)*

Given the recordings from two class distributions, the goal of CSP is to find the spatial filters from a linear combination of a multichannel signal[3] which maximizes variance for one class and minimizes variance for the second class simultaneously. To achieve this, spatial patterns are determined using simultaneous diagonalization of the covari-

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