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Classification of EEG-based single-trial motor imagery tasks using a B-CSP method for BCI

Key words: Electroencephalogram (EEG); Motor imagery (MI); Improved common spatial pattern (B-CSP); Feature extraction; Classification

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Motivation

1. Motor imagery (MI) EEG, as a new communication approach, has been widely used in BCI applications.

2. The low signal-to-noise ratio and individual differences of EEG can affect the classification results negatively. Therefore, how to define and extract appropriate features for effectively translating and encoding MI EEG is a challenge to classify EEG-based MI tasks.

3. Most methods like conventional CSP are used to extract EEG features from the specific and fixed frequency bands. However, for different people, the ERD/ERS patterns will occur in different frequency bands; even for each electrode, the optimal frequency bands are different.

Main idea

1. We can use ERD/ERS patterns caused by MI of different limbs (left hand movement versus right hand movement versus foot movement) to classify EEG and obtain control signals of external applications.

2. For different people, the optimal frequency band of each electrode is obtained before feature extraction.

3. An improved common spatial pattern (B-CSP) method is designed and implemented.

4. The proposed method is validated by the public data set and experimental data set, and is compared with another two conventional feature extraction methods (CSP and AR).

Method

1. For different subjects, the method of Bhattacharyya distance is used to select the optimal frequency band of each electrode including strong ERD and ERS patterns.

2. The signals of the optimal frequency band are decomposed into spatial patterns, and the features that can describe the maximum differences of two classes of MI are extracted from the EEG data.

Major results

1. Confusion matrix results of three feature extraction methods

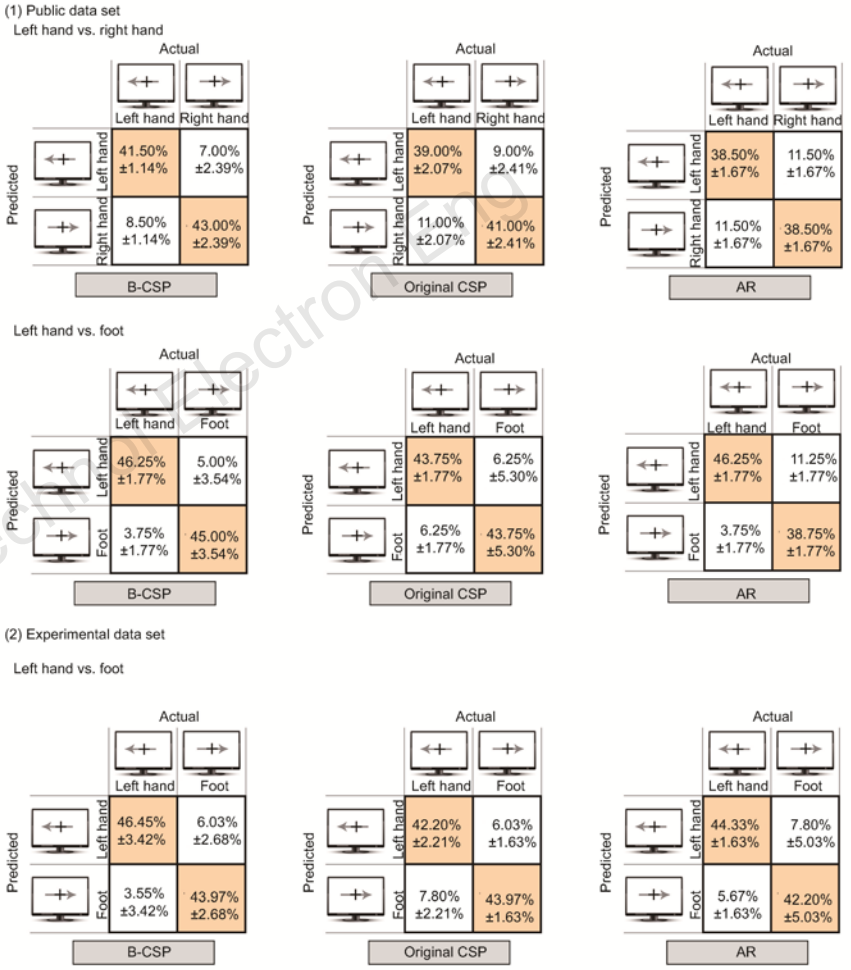

Fig. 6 Confusion matrix results of three feature extraction methods using the same two testing sets of data. The values of each element of the confusion matrix mean the average value (upper number) and standard deviation (lower number) over all subjects. The color element represents the correct classification percentage, and the white element represents the wrong classification percentage. References to color refer to the online version of this figure

Major results (Cont'd)

2. Accuracies of three feature extraction methods

Table 1 Accuracies of three feature extraction methods using the same testing sets of two data sets (all subjects)

Data set	Subject	Accuracy (%)		
		B-CSP	Original CSP	AR
Public data set (left hand vs. right hand)	ds1b	82.50	80.00	67.50
	ds1c	92.50	75.00	82.50
	ds1d	80.00	82.50	75.00
	ds1e	80.00	75.00	82.50
	ds1g	87.50	87.50	77.50
	Average	84.50±5.42	80.00±5.30	77.00±6.22
Public data set (left hand vs. foot)	ds1a	90.00	90.00	82.50
	ds1f	92.50	85.00	87.50
	Average	91.25±1.77	87.50±3.54	85.00±3.54
Experimental data set (left hand vs. foot)	Subject 1	94.68	84.04	86.17
	Subject 2	86.17	88.30	80.85
	Subject 3	90.43	86.17	92.55
	Average	90.43±4.26	86.17±2.13	86.52±5.86

Major results (Cont'd)

3. ROC curves of three feature extraction methods using testing sets of ds1a (public data set)

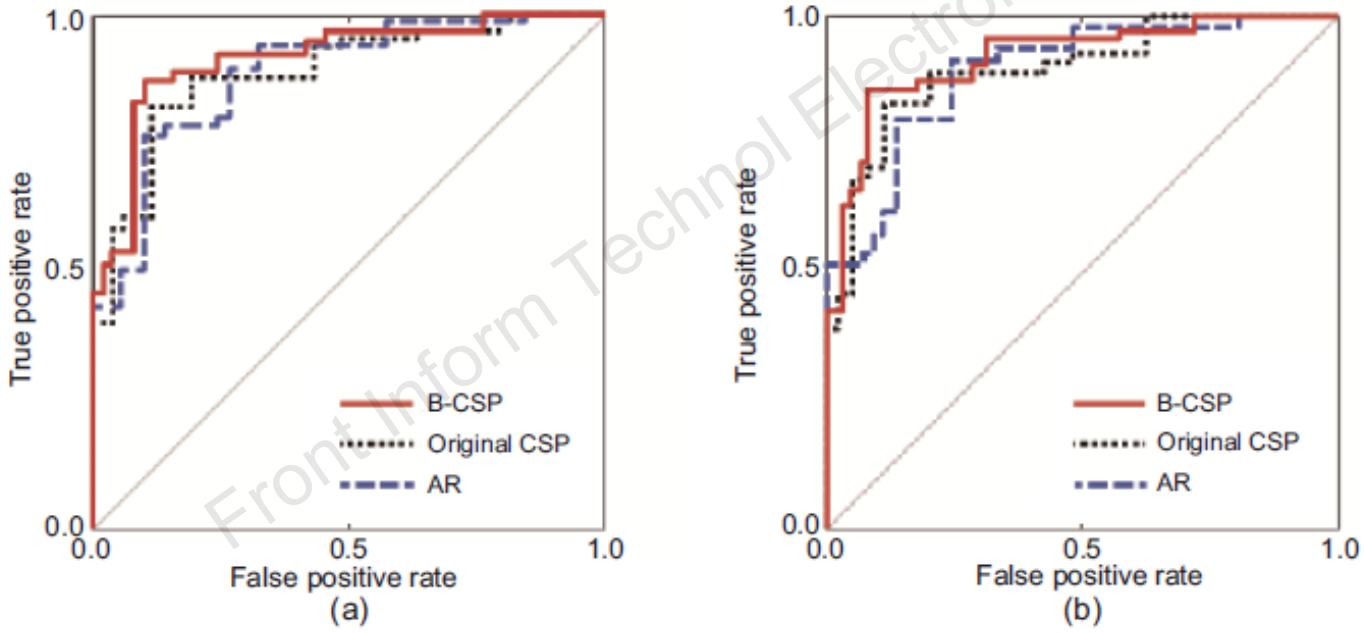

Fig. 7 Receiver operating characteristic (ROC) curves of three feature extraction methods using testing sets of ds1a (public data set) (a) and subject 2 (experimental data set) (b)

Major results (Cont'd)

4. Precision, recall, and *F*-score values of each class of MI using three methods

Table 2 Precision, recall, and *F*-score values of each class of MI using three methods (all subjects)

Data set	Subject	Evaluation	B-CSP		Original CSP		AR	
			Left hand	Foot/ right hand	Left hand	Foot/ right hand	Left hand	Foot/ right hand
Public data set (left hand vs. right hand)	ds1b	Precision	0.8095	0.8421	0.8750	0.7500	0.6842	0.6667
		Recall	0.8500	0.8000	0.7000	0.9000	0.6500	0.7000
		F-score	0.8293	0.8205	0.7778	0.8182	0.6667	0.6829
	ds1c	Precision	0.9474	0.9048	0.8125	0.7083	0.8095	0.8421
		Recall	0.9000	0.9500	0.6500	0.8500	0.8500	0.8000
		F-score	0.9231	0.9268	0.7222	0.7727	0.8293	0.8205
	ds1d	Precision	0.7727	0.8333	0.7826	0.8824	0.7500	0.7500
		Recall	0.8500	0.7500	0.9000	0.7500	0.7500	0.7500
		F-score	0.8095	0.7895	0.8372	0.8108	0.7500	0.7500
	ds1e	Precision	0.8000	0.8000	0.7083	0.8125	0.8824	0.7826
		Recall	0.8000	0.8000	0.8500	0.6500	0.7500	0.9000
		F-score	0.8000	0.8000	0.7727	0.7222	0.8108	0.8372
	ds1g	Precision	1.0000	0.8000	0.9412	0.8261	0.7391	0.8235
		Recall	0.7500	1.0000	0.8000	0.9500	0.8500	0.7000
		F-score	0.8571	0.8889	0.8649	0.8837	0.7907	0.7567
Public data set (left hand vs. foot)	ds1a	Precision	0.8636	0.9444	0.9444	0.8636	0.7826	0.8824
		Recall	0.9500	0.8500	0.8500	0.9500	0.9000	0.7500
		F-score	0.9048	0.8947	0.8947	0.9047	0.8372	0.8108
	ds1f	Precision	0.9474	0.9048	0.8182	0.8889	0.8261	0.9412
		Recall	0.9000	0.9500	0.9000	0.8000	0.9500	0.8000
		F-score	0.9231	0.9268	0.8571	0.8421	0.8837	0.8649
Experimental data set (left hand vs. foot)	Subject 1	Precision	0.9375	0.9565	0.8478	0.8333	0.8269	0.9048
		Recall	0.9574	0.9362	0.8298	0.8511	0.9149	0.8085
		F-score	0.9474	0.9462	0.8387	0.8421	0.8687	0.8539
	Subject 2	Precision	0.8696	0.8542	0.8750	0.8913	0.7843	0.8372
		Recall	0.8511	0.8723	0.8936	0.8723	0.8511	0.8298
		F-score	0.8602	0.8632	0.8842	0.8817	0.8163	0.8335
	Subject 3	Precision	0.8519	0.9750	0.9048	0.8269	0.9545	0.9000
		Recall	0.9787	0.8298	0.8085	0.9149	0.8936	0.9574
		F-score	0.9109	0.8966	0.8539	0.8687	0.9231	0.9278

Conclusions

1. An improved common spatial pattern (B-CSP) method to extract features has been designed for alleviating the adverse effects of low SNR and individual differences.

2. An improved classification performance for both data sets verified the advantages of the B-CSP method over conventional methods.

3. The proposed B-CSP method can classify EEG-based MI tasks effectively, and this study provides practical and theoretical approaches to BCI applications.