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Enhanced Motor Imagery Classification in EEG-BCI using Multivariate EMD based filtering and CSP Features

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Introduction: The electroencephalogram (EEG) signal tends to have poor time-frequency localization when analysis techniques involve fixed set of basis function such as short-time Fourier transform (STFT) and wavelet transform (WT). It also exhibits highly non-stationary characteristics and suffers from low signal-to-noise ratio (SNR). As a result, there is often poor task detection accuracy and high error rates in brain-computer interfacing (BCI) systems. In this work, we have extended the multivariate empirical mode decomposition (MEMD) [1] by filtering the intrinsic mode functions (IMFs) based on mean frequency measure to obtain an enhanced BCI. Hence, we present a novel filtering technique, namely, MEMD based band-pass filtering (MEMDBF), in order to handle the inherent non-stationarity and utilize the cross channel information present in a multi-channel EEG based BCI.

Methodology: Standard empirical mode decomposition (EMD) suffers from the problem of mode-mixing where the similar frequencies occur in different IMFs. The MEMD handles this problem and allows to achieve high localization of information pertaining to specific frequency-bands. It decomposes the raw EEG signal into a finite set of frequency modulated (FM) and amplitude modulated (AM) components known as IMFs [1]. It provides the same number of IMFs for all the data channels in the time domain. We have considered fifteen channels (i.e., FC3, FC1, FCz, FC2, FC4, C3, C1, Cz, C2, C4, CP3, CP1, CPz, CP2 and CP4) for the analysis. Further, the candidate IMFs are selected based on the mean frequency measure calculation corresponding to mu (8-12 Hz) and beta (16-24 Hz) rhythms. The enhanced IMF is obtained by summation of all the candidate IMFs. This filtering is done ahead of feature extraction and classification steps. Its goal is to provide better feature separability, leading to reduced error rates and high task classification accuracy in a motor imagery (MI) based BCI. Then we have applied spatial filters which maximize the variance in one class and minimize in the other class, and computed CSP features using first and last two pairs of spatial filters from the enhanced EEG signals and a linear discriminant analysis (LDA) classifier is used to classify the feature sets into left and right hand MIs.

Results: Table 1 demonstrates the effectiveness of the proposed method in terms of two class MI task classification accuracy when evaluated on the BCI competition IV dataset 2A[#]. The classification accuracy in the training stage has been computed as 5-fold cross-validation. Notably, eight of the nine subjects have shown improvement and also the average of classification accuracy has improved in the evaluation stage (> 6.9 %). We have obtained a mean kappa value of 0.54 across all of the nine subjects for a two class MI classification. This however, cannot be compared with the competition winner, who reported 0.569 mean kappa value [2] for a different four class classification problem.

Discussion: This initial investigation demonstrates that the non-stationary phenomenon present in EEG signals has been reduced to some extent as evidenced by significantly higher classification accuracy in the evaluation session obtained on the BCI competition IV dataset 2A. Also, it has been verified that the shift in the input data distribution across sessions has been reduced because of the MEMDBF, as the training and evaluation input data distributions have zero mean. The scope of future work will include proposing new non-linear features based on IMFs of EEG signals for multiclass classification of MI based BCI.

TABLE 1. Classification accuracies (%) obtained with the proposed MEMD based filtering and raw EEG data.

Subjects		A01	A02	A03	A04	A05	A06	A07	A08	A09	Average	*p* value*
MEMDBF	Training	88.14	65.39	92.38	79.82	63.23	78.54	80.58	95.12	87.44	81.18	0.2683
	Evaluation	**90.28**	**59.72**	**93.06**	**70.14**	**52.78**	**61.81**	**75**	95.83	**92.36**	76.77	0.0166
Raw EEG	Training	72.27	63.21	91.65	71.58	67.92	67.99	86.18	95.19	88.86	78.32	-
	Evaluation	69.44	50	90.28	59.03	50	54.86	65.28	97.92	91.67	69.83	-

**Two-way analysis of variance (ANOVA2) test has been used to compute p-value.*

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