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Shallow convolutional neural network with rank-1 Fourier domain weights for brain signal classification

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Abstract: Magnetic field strength and electric potential recorded on scalp (or in its proximity) by magneto- and electro-encephalography (M/EEG) devices are direct measures of the brain activities. M/EEG devices are broadly used in brain-computer interfaces (BCI), evaluation of multiple neurological diseases, cognitive science, analysis of dynamic brain networks, etc. Active and passive BCI applications, as well as characterization of certain neurological disorders such as epilepsy, require employment of M/EEG signal classifiers. Under the assumptions that a multivariate M/EEG signal can be represented as sum of the rank-1 multivariate signals corresponding to the individual brain activities and noise and that the relevant brain waveforms are of transient and recurrent nature, we propose a shallow convolutional neural network (CNN) classifier. Proposed model contains rank-1 trainable spatial and temporal weights, regularized by the representation in the Fourier domain. The model is evaluated on the problems of active and passive BCI.

M/EEG signals

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Low signal to noise ratio
(subject alertness, sensor positions, head geometries, cortex properties)

High inter-session and inter-subject variability
(measuring device imperfections, artifacts from other organs, ambient noise)

M/EEG signals

Shallow CNN classifier with rank-1 Fourier domain weights

Given an M/EEG signal $x \in \mathbb{R}^{C \times T}$, where $C$ and $T$ are the number of sensors and time instants, the following assumptions are made:

1) $X$ can be modeled as a sum of rank-1 signals associated to individual sources and noise $\{\tau, n\}$ as

$$X = \sum_{k=1}^{K} u_k \tau_k^* + N.$$ 

$K$ is the number of sources, $u_k \in \mathbb{R}^C$ is topographic map, $\tau_k \in \mathbb{R}^T$ is source signal. $N \in \mathbb{R}^{C \times T}$ is noise.

2) Given a recurrent and transient nature of the brain waveforms $[3, 4]$, a source signal $k$ can be represented as $x_k = v_k \tau_k^* + z_k \tau_k$, where $z_k \in \mathbb{R}^{C \times T}$ is a sparse vector of activations.

3) A head can be modeled as a sphere $[5]$, thus $u_k$ can be represented in terms of spherical harmonics (SH) as $u_k = Y_0^0 \hat{u}_k \in \mathbb{R}^C$ contains SH coefficients and $Y \in \mathbb{R}^{C \times C}$ contains $N \times C$ basis elements. Thus

$$\hat{X} = \sum_{k=1}^{K} \hat{u}_k \tau_k^* + \hat{N}$$

4) Waveforms can be expressed in terms of discrete cosine (DC) basis as $v_k = C_k \gamma_k \in \mathbb{R}^C$ contains DC coefficients. $C \in \mathbb{R}^{C \times T}$ contains DC basis. $F$ is the number of DC basis elements.

Model characteristics

Feature classification:
- correlation with rank-1 kernels
- batch-normalization

Feature selection:
- ReLU (thresholding)
- max-pooling

Feature extraction:
- single fully connected layer
- BCI setup:

https://gitlab.inria.fr/ssedlar/shallow_cnn_meg

4 Conclusions

In this work we have proposed a compact shallow CNN with rank-1 trainable parameters regularized by representation in the Fourier domain.

The experiments conducted on the MEG and EEG active and passive BCI problems showed that our model achieves comparable or higher classification accuracy than the state-of-the-art CNN models while preserving a low number of trainable parameters.

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5 References:

[3] Dugast La Tour, T. et al., Advances in NIPS, 2018
[5] Vatta F. et al., Computational intelligence and neuroscience, 2010
[8] Himma, M. F. et al., Conference on NER, 2021
[10] Lawhern, V. J. et al., Journal of neural engineering, 2018