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للبحـــث والابتكـــار والموهبـــة

Physics-inform attention temporal convolutional network for EEG-based motor imagery classification

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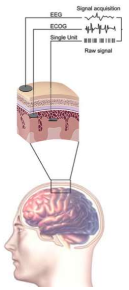
Introduction

- The brain-computer interface (BCI) is an emerging technology that has the potential to transform the world, with a wide range of applications ranging from medical applications to human augmentation. MI-EEG signal has been used in many BCI applications to assist disabled people and to augment human capabilities.

- EEG is a non-invasive, low cost, low risk, and portable method that records the electrical activities of the brain. Motor imagery (MI) is the activity of thinking about moving a human body part without physically moving it.



- Recognizing human intention from EEG signal is challenging due to the low SNR ratio and various sources of artifacts, the recorded EEG signal is only ~ 5% of the actual brain signal.

Aims

The goal is to develop a high-performance attention-based deep learning model to classify EEG-based MI brain signals, which outperform state-of-the-art models.

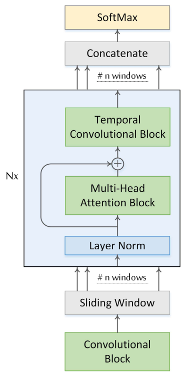
Proposed Method

The proposed model consists of three main blocks:

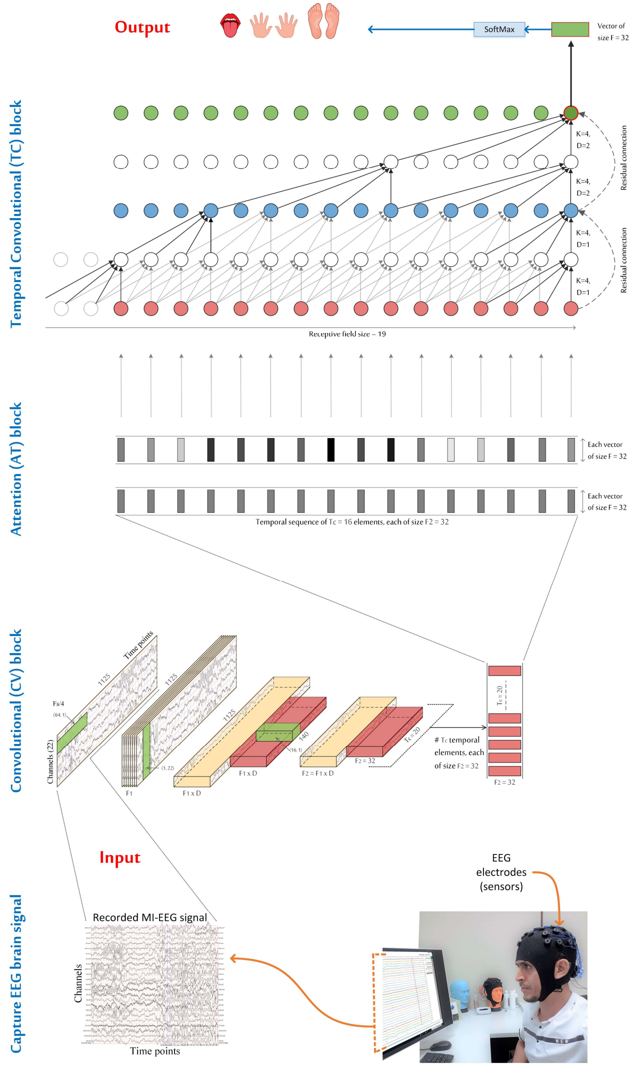
Convolutional (CV) block: encodes low-level spatio-temporal information within the MI-EEG signal into a sequence of high-level temporal representations through three convolutional layers.

Attention (AT) block: highlights the most important information in the temporal sequence using a multi-head self-attention (MSA).

Temporal convolutional (TC) block: extracts high-level temporal features from the highlighted information using a temporal convolutional layer



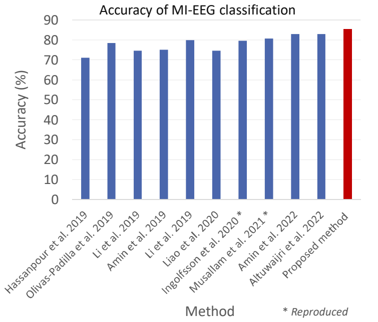
The proposed model also utilizes the convolutional-based sliding window to augment MI data and boost the performance of MI classification efficiently.



Visualization of the components of the proposed ATCNet model. ATCNet consists of three main blocks: the convolutional (CV) block, the multi-head self-attention (AT) block, and the temporal convolutional (TC) block.

Results

- The proposed ATCNet model achieves an overall accuracy of 85.38% and a κ-score of 0.81, using the challenging and benchmark BCI Competition IV-2a dataset, which outperforms the state-of-the-art techniques by at least 2.51%.
- Ablation analysis showed that each block adds its contribution: the AT block increased the overall accuracy by 1.54% and SW by 2.28%. The addition of the TC block also increased accuracy by 1.04% compared to using the CV block only.



Ablation analysis: contribution of each block in the ATCNet model. AT: attention, SW: sliding window, TC: temporal convolution.

Removed block	Accuracy %	κ-score
None (ATCNet)	85.38	0.805
AT	83.84	0.784
SW	83.10	0.775
SW + AT	82.75	0.770
TC	79.44	0.726
SW + TC	80.48	0.740
AT + TC	82.60	0.768
SW + AT + TC	81.71	0.756

Conclusions

- This study proposed a novel attention-based temporal convolutional network (ATCNet) for EEG-based motor imagery classification that outperformed state-of-the-art techniques in MI-EEG classification using the BCI-2a dataset with an accuracy of 85.4% and 71% for the subject-dependent and subject-independent modes, respectively. These high results came with a relatively small number of parameters (115.2K), which makes ATCNet applicable to limited devices.
- The ablation analysis showed that each block in the ATCNet model made a significant contribution to the performance of the ATCNet model.
- The proposed model demonstrated a powerful ability to extract MI features from a raw EEG signal without pre-processing using a limited-size and challenging dataset.

Future work

- The proposed model can be further improved by using attention mechanisms in several domains, i.e., temporal, spectral, and spatial domains.
- The proposed model can also be refined using preprocessing methods to remove artifacts and deep generative models to increase the size of the dataset.

Theme of scientific research
Basic Science and Engineering Research Track