

Evolving EEG signal processing techniques in the age of artificial intelligence

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(Guest Editors)

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Electroencephalogram (EEG) is an important technique for measuring population-level electrical activity arising from the human brain. Due to its exquisite temporal sensitivity and implementation simplicity, EEG has been widely applied to dynamically evaluate the function of the brain. Being responded to a specific sensory, cognitive, or motor event, the changes of EEG signals give rise to evoked potentials (EPs) and event-related potentials (ERPs), which are highly associated with different brain functions, e.g., perception, emotion, and cognition. These advances make the EEG technique popularly used in various basic and clinical applications. To make full use of the EEG technique, signal processing and machine learning methods are crucial in the extraction of information for better understanding the cerebral functioning. Particularly, in this age of artificial intelligence (AI), rapidly developed AI methods, such as convolutional neural networks and recurrent neural networks, have been applied to EEG signals and have achieved promising performance in many real applications. As a consequence, the field of EEG signal processing has undergone significant growth in the last few years, and the scope and range of practical applications of EEG, such as

brain–computer interface (BCI), are steadily increasing. For this reason, the special issue aims to provide a collection of papers discussing the conceptual and methodological innovations as well as practical applications of the EEG techniques.

This special session has included seven review papers contributed by experts in this interdisciplinary field, and all authors have worked in the fields of EEG processing methods and applications for many years.

First of all, Li [1] shared his insightful and constructive thoughts on EEG signal analysis and classification. Specifically, he focused on several important and emerging topics in EEG processing, such as brain connectivity, tensor decomposition, multi-modality, deep learning, big data, and naturalistic experiments. These topics, particularly those AI-related topics, are both crucial and promising for the future advancement of EEG signal analysis and classification.

Next, this special issue presented several papers concerning the applications of EEG in psychology, emotion recognition, and BCI. One important and conventional application field of EEG is psychology, in which EEG has been extensively used to decode the psychological

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variables and mental states of human beings. However, many psychologists may have no background in signal processing, so that they cannot correctly use signal processing methods to extract useful and relevant EEG features to fulfill their research purposes. To bridge this gap, Li et al. [2] and Zhang et al. [3] provided two introductory and critical essays discussing how to properly use signal processing methods to extract useful information from resting-state and task-related EEG activities, respectively. These two papers were prepared with psychologists as a target audience, so the authors provided detailed and complete data analysis pipelines that are easy to understand and follow. These two papers also highlighted the remarkable differences between resting-state EEG and task-related EEG in their methods, features, and applications.

EEG-based emotion recognition has become a promising research direction with significant application value in recent decades. In Hu et al. [4], a systematical introduction of current available video-triggered EEG-emotion databases with the corresponding signal processing methods was presented. They summarized that improving the construction of EEG-emotion database and developing more robust and generalized EEG-based emotion recognition models could greatly promote the application of real-time emotion detection and regulation.

EEG is the most popular brain imaging technique to acquire brain signals in BCI applications, and signal processing always plays an essential role in translating EEG encoded users' intentions into commands that can be executed by external machines. However, practical applications of BCI are impeded by many factors, and one important issue is the BCI inefficiency phenomenon, which means a proportion of subjects cannot achieve sufficiently high accuracy in using BCI.

Focusing on the subject inefficiency phenomenon of motor-imagery BCI, Zhang et al. [5] proposed some potential solutions include transfer learning algorithms, new experimental paradigms, mindfulness meditation practice, novel training strategies, and identifying new motor imagery-related EEG features. All these solutions are promising in reducing the percentage of inefficient subjects, which can significantly expand the value and impact of EEG-based BCI.

With the advancement of AI, there are growing interests not only in the utilization of AI methods for EEG decoding in BCI, but also in AI-related visual, literal, and motion applications of BCI. Cao [6] provided a comprehensive and up-to-date review on the use of AI technologies for BCI. On the one hand, he introduced recent trends of using AI models, such as transfer learning and generative adversarial networks, to analyze EEG signals for better performance of BCI. On the other hand, he reviewed EEG-based BCI applications inspired by mainstream AI topics, such as computer vision, natural language processing, and robotics.

Last but not least, the performance and impact of EEG applications do not only rely on methodological developments but are also advanced by hardware. Technological advances in the semiconductor industry and the increasing demand for wearable devices have enabled the development of dedicated chips for complex EEG signal processing with smart functions and AI-based classifications. Shi et al. [7] introduced and reviewed the state-of-the-art dedicated chip designs for EEG processing, particularly for wearable systems. Furthermore, the authors expected more AI-based elements could be integrated into a small long-battery-life wearable EEG system in the future with powerful functions in signal processing.

In summary, this special issue covers a wide range of topics of EEG processing, but with a focus on AI-related techniques. We can see from these papers that AI-related signal processing methods have already greatly improved the performance of many EEG applications. Furthermore, AI technologies have inspired and enabled some new EEG applications. We hope our readers can get useful information from this special issue, and we would also like to thank all the authors for their significant contribution to this special issue.

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