applied sciences

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*Editorial*

# Special Issue "Advances in Neuroimaging Data Processing"

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## 1. Introduction

The development of in vivo neuroimaging technology has led to an incredible amount of digital information concerning the brain. Neuroimaging techniques are being increasingly used to study human cognitive processes [1] and create brain–machine interfaces [2], as well as to identify and diagnose certain brain disorders [3]. Currently, neuroscientists and physicians actively use various methods of brain scanning, including electroencephalography (EEG), magnetoencephalography (MEG), functional near-infrared spectroscopy (fNIRS), electrocorticography (ECoG), functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and diffusion tensor imaging (DTI). Recent advances in signal processing and machine learning applied to neuroimaging data using various signal-processing methods have led to impressive progress towards solving several practical problems in medicine, healthcare, neuroscience, biomedical engineering, brain–machine interfaces, cognitive science, etc.

## 2. Advanced Methods of Neuroimaging-Based Data Processing

In light of the foregoing discussion, this Special Issue collects original papers on theoretical and experimental results highlighting the recent advances in neuroimaging-based data processing using theories, algorithms, architectures, and applications. Various topics are covered herein, mainly those related to the restoration of functional brain networks, the processing of EEG and MEG brain activity, brain state monitoring including brain–computer interfaces (BCIs) and external device control, and the development of open-source software tools.

One of the most important tasks of neuroimaging is the restoration of functional brain networks [4,5]. Therefore, three out of ten articles in this Special Issue are devoted to the analysis and development of methods for restoring functional brain networks [6–8]. In the first paper, Faes, Vantieghem, and Van Hulle [6] propose a new approach to source reconstruction from EEG data. Their method is based on directed connectivity estimation using deep learning. The authors apply several types of artificial neural networks to estimate directed connectivity and assess its accuracy with respect to several ground truths. They show that an LSTM neural network with non-uniform embedding yields the most promising results due to its relative robustness to differing dipole locations. In the second paper, Maher et al. [7] discuss the application of multimodal neuroimaging data to revealing connectivity patterns in the onset of seizures. The authors obtain structural connectomes from diffusion MRI (dMRI) and functional connectomes from EEG to assess whether high structure–function coupling corresponds to the seizure onset region. They argue that dMRI combined with EEG can improve the identification of the seizure onset region. Their study is a good example of dMRI's potential in clinical practice. Finally, in the third paper, Chen et al. [8] present a new method for constructing complex networks to assess cognitive load. Their approach is based on cross-permutation entropy.



**Citation:** Hramov, A.E.; Pisarchik, A.N. Special Issue "Advances in Neuroimaging Data Processing". *Appl. Sci.* **2023**, *13*, 2060. https://doi.org/10.3390/app13042060

Received: 3 February 2023
Accepted: 3 February 2023
Published: 5 February 2023

Traditional research tasks in the field of neuroimaging include time series analysis of brain activity recordings. In this regard, Pavlov et al. [9] discuss the possibility of detecting changes in brain electrical activity associated with sleep deficit using extended detrended fluctuation analysis (EDFA). By applying this approach to EEGs in mice, they identify signs of changes that could be caused by short-term sleep deprivation. In another paper, Chholak et al. [10] analyze the neurophysiological data of MEG experiments based on the visual perception of flickering ambiguous stimuli. The results support their hypothesis of a correlation between event-related coherence in the visual cortex and neuronal noise and suggest that greater brain involvement in visual stimuli is accompanied by stronger brain noise.

Several papers in this Special Issue involve the active development of neurotechnology. Specifically, in their paper, De La Pava Panche et al. [11] present a new method for estimating phase transfer entropy (TE) between distinct pairs of instantaneous phase time series to enable real-time estimation, which is important for the development of TE application strategies for BCIs. In another paper, Kuc et al. [12] propose a monitoring system that facilitates the evaluation of behavioral performance (decision time and errors) during a prolonged visual classification task. The results of this work enable the determination of whether changes in pre-stimulus neural activity, as measured by EEG power, predict behavioral characteristics. In the following article, Van Den Kerchove et al. [13] consider the problem of the usability of EEG-based visual BCIs using event-related potentials (ERPs). They introduce two regularized estimators for beamformer weights that are well conditioned despite using limited training data and improve ERP classification accuracy to reduce calibration time and required EEG data before BCI operation. Along with the rapid development and exploitation of methods for the real-time processing of brain activity, these estimators' roles in solving the problems of the rehabilitation of patients suffering from brain injuries or helping people with disabilities are becoming essential, as also highlighted in the paper by Ngo and Nguyen [14], who propose an EEG-based wheelchair control system using a grid map designed to enable people with disabilities to reach any given destination.

Finally, Sánchez-Cifo, Montero, and López [15] describe a developed open-source tool called MuseStudio that allows one to import and export data from brain-sensing headband EEG devices and view and analyze brain data in real time.

## 3. Future of Neuroimaging Data Processing: Is the Era of Machine Learning Coming?

In recent years, significant progress has been achieved regarding the methods of analysis and processing of neuroimaging data, primarily through the use of machine learning. Recently, machine learning has gained popularity in neuroscience due to its ability to recognize hidden patterns and nonlinear relationships in large volumes of nonstationary and ambiguous neuroimaging data. Soon, biologists and mathematicians can anticipate the greater use of machine learning approaches to gain new insights into brain behavior and neurotechnology applications, including BCIs. Machine learning is of particular interest for the medical diagnosis of neurological diseases, where it is a powerful tool for the early detection of biomarkers of various neurological disorders [16]. At the same time, appropriate methods and approaches regarding explainable artificial intelligence (XAI) should be ready for the integration and use for neuroimaging-based data processing in modern digital medicine [17,18].

**Funding:** This research was funded by Program 'Priority-2030' of Immanuel Kant Baltic Federal University of Ministry of Education and Science of Russian Federation.

**Acknowledgments:** We thank all authors and peer reviewers for their valuable contributions to this Special Issue. We are also grateful to the MDPI management and staff for their tireless editorial support for this project, which led to its successful completion, and for the launch of an open-access international peer-reviewed journal, *Applied Sciences*, covering all aspects of applied natural science.

**Conflicts of Interest:** The authors declare no conflict of interest.

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