Generalization of Deep Neural Networks for EEG Data Analysis

by

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Certificate of Authorship and Originality

This is to certify that this thesis is submitted in fulfilment of the requirements for award of Doctoral of Philosophy, in the School of Computer Science, Faculty of Engineering and Information Technology, University of Technology Sydney.

This thesis is wholly the author's own work unless otherwise referenced or acknowledged. In addition, the author certifies that all information sources and literature used are indicated in this thesis. This document has not been previously submitted for qualification of a degree in any other academic institution.

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Abstract

Electroencephalography (EEG) facilitates the neuroscientific research and applications by virtue of its properties such as non-invasion, affordability, mobility, etc. However, challenges including high artefacts pending, intra- and cross-subject variance, limited data availability, etc., pose the difficulty in reaching solid conclusions. This thesis explores how to utilize and generalize deep neural networks (DNN), which have set new performance records in various fields, to analyze EEG data to mitigate these challenges in reaching enlightening conclusions.

This thesis brings the comprehension of research goals by the introduction of EEG and DNN background. It reviews the conventional EEG signal processing methods and highlights the challenges of EEG data analysis. As part of this work, EEG datasets from three stereotypical brain-computer interface (BCI) experiments are described in detail to assess the proposed methods by benchmarking. To illustrate the DNN centered methodology for addressing divergent challenges of EEG data analysis, a research map is compassed to show respective contributions in fulfilling the following specific goals: (1) Selection of appropriate DNN structures targeting EEG data captured during different BCI experiments. (2) Solutions to address the intra- and cross-subject variance of EEG data. (3) Utilization of brain-inspired computation such as memory network to improve the performance of processing EEG data. (4) Exploration of new computation paradigm, i.e., reinforcement learning (RL), to relieve the noise label challenge and to improve data utilization.

By a series of published and in-preparation papers, this thesis demonstrates different achievements corresponding to the set goals: (1) Investigation of the computation traits of neural network structures and revelation of their effectiveness in EEG signal processing. The designed recurrent residual network (RRN), which is based on the recurrent structure, residual structures, etc., achieves the highest classification accuracy and provides coherent evidence and interpretation to the efficacy of conventional hand-crafted filters. (2) Invention of adversarial method in light of the domain adaptation (DA) and generative adversarial network (GAN) to address inter- and cross-subject variance. The proposed subject adaptation network (SAN), which borrows the philosophy of GAN but works in different ways, shows promising results among EEG sample clustering, sample-of-interest selection, EEG data alignment, etc. (3) Systematic study of memory networks and proposal of memory module based on self-organized maps (SOM). Work on a stacked version of differentiable neural computer (DNC), reveals that EEG features buried in the endurance experiment can be more effectively harvested by augmenting memory and consequently boost the performance. SOM-based memory network demonstrates its capability in reducing network complexity. (4) Implementation of reinforcement learning (RL) for EEG data analysis to relieve the noisy label challenge and to improve EEG data utilization. Instantiation of RL framework such as deep Q-network (DQN) demonstrates its feasibility and practicability for certain BCI experiments. Generally, through this sequence of work and papers, this thesis contributes from different aspects that well advance the EEG data analysis via DNN.

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Publications

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- Yurui Ming, Yu-Kai Wang, Mukesh Prasad, Dongrui Wu and Chin-Teng Lin, "Sustained Attention Driving Task Analysis based on Recurrent Residual Neural Network using EEG Data," IEEE International Conference on Fuzzy Systems, 2018.

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List of Abbreviations

ANN ·········· Artificial Neural Networks
BCI············ Brain Computer Interface
CNN ·········· Convolutional Neural Networks
DA ············ Domain Adaptation
DL············· Deep Learning
DNN ·········· Deep Neural Networks
DNC ·········· Differentiable Neural Computer
DQN ·········· Deep Q-Network
DRL··········· Deep Reinforcement Learning
EEG ·········· Electroencephalography
GAN ········· Generative Adversarial Networks
LSTM········· Long Short-term Memory
ML ············ Machine Learning
MN ··········· Memory Network
RL ············ Reinforcement Learning
RNN ·········· Recurrent Neural Networks
SAN ·········· Subject Adaptation Network
SL ············· Supervised Learning
SOM ·········· Self-organizing Maps

Content