Tutorial

Title

Transfer Learning for EEG-based Brain-Computer Interfaces

Abstract

A brain-computer interface (BCI) enables a user to communicate directly with an external device, e.g., a computer, using brain signals. It can be used to research, map, assist, augment, or repair human cognitive or sensory-motor functions. A closed-loop BCI system performs signal acquisition, temporal filtering, spatial filtering, feature engineering and classification, before sending out the control signal to an external device. Transfer learning (TL) has been widely used in EEG-based BCIs to reduce the calibration effort for a new subject, greatly increasing their utility. This tutorial describes how TL can be considered in as many components of a BCI system as possible, and introduces a complete TL pipeline for EEG-based BCIs. Deep learning approaches are also fully evaluated with classic and state-of-the-art domain adaptation approaches with end-to-end neural networks for both offline and online BCI applications. Examples on multiple datasets demonstrate the advantages of considering TL in multiple components of EEG-based BCIs. Especially, integrating data alignment and sophisticated TL approaches can significantly improve the classification performance, and hence greatly reduces the calibration effort.

Duration

TWO-hours.

Motivation

Electroencephalogram (EEG) based brain-computer interfaces (BCIs) are used in many applications, due to their low-risk, low-cost, and convenience. Because of EEG's high variations across subjects and sessions, a long calibration session is usually needed to adjust the system before each use, which is time-consuming and user-unfriendly. Transfer learning (TL) has been widely used in EEG-based BCIs to reduce the calibration effort for a new subject, greatly increasing their utility. Successful application requires carefully adding TL components in the complete pipeline for closed-loop EEG-based BCIs. It has been attracting lots of research interests recently.

Expected audience

Basic knowledge of brain-computer interface and machine learning. Audience with backgrounds in neuroscience, computer science, electrical engineering, artificial intelligence, etc., are all welcomed to attend the tutorial.

Outline of contents

1. Introduction to brain-computer interfaces (BCIs)
2. Transfer learning for BCIs
   - Transfer learning concept
   - Euclidean alignment
   - Pre-alignment strategy
   - Common spatial pattern (CSP)
   - Combined CSP
   - Regularized CSP
   - ReliefF
   - Combined ReliefF
   - Weighted Adaptation Regularization (wAR)
   - Online wAR
   - Offline deep domain adaptation
   - Online deep domain adaptation
3. Experiments
   - MI datasets
   - Algorithms
   - Experimental settings
   - Experimental results
4. Conclusions and future research

Key references

1. D. Wu*, X. Jiang and R. Peng, "Transfer Learning for Motor Imagery Based Brain-Computer Interfaces: A Tutorial," Neural Networks, 153:235-253, 2022.

2. D. Wu*, Y. Xu and B-L Lu, "Transfer Learning for EEG-Based Brain-Computer Interfaces: A Review of Progress Made Since 2016," IEEE Trans. on Cognitive and Developmental Systems, 14(1):4-19, 2022.

3. R. Bian, H. Wu, B. Liu and D.Wu*, "Small Data Least-Squares Transformation (sd-LST) for Fast Calibration of SSVEP-based BCIs," IEEE Trans. on Neural Systems and Rehabilitation Engineering, 2023, in press.

4. W. Zhang, Z. Wang and D. Wu*, "Multi-Source Decentralized Transfer for Privacy-Preserving BCIs," IEEE Trans. on Neural Systems and Rehabilitation Engineering, 2023, in press.

5. W. Zhang and D.Wu*, "Lightweight Source Free Transfer for Privacy-Preserving Motor Imagery Classification," IEEE Trans. on Cognitive and Developmental Systems, 2023, in press.

6. W. Zhang, L. Deng, L. Zhang and D. Wu*, "A survey on Negative Transfer," IEEE/CAA Journal of Automatica Sinica, 10(2):305-329, 2023.

7. K. Xia, L. Deng, W. Duch and D.Wu*, "Privacy-Preserving Domain Adaptation for Motor Imagery-based Brain-Computer Interfaces," IEEE Trans. on Biomedical Engineering, 69(11):3365-3376, 2022.

8. W. Zhang and D.Wu*, “Manifold Embedded Knowledge Transfer for Brain-Computer Interfaces,” IEEE Trans. on Neural Systems and Rehabilitation Engineering, 28(5), pp. 1117-1127, 2020.

9. H. He and D.Wu*, “Different Set Domain Adaptation for Brain-Computer Interfaces: A Label Alignment Approach,” IEEE Trans. on Neural Systems and Rehabilitation Engineering, 28(5):1091-1108, 2020.

10. H. He and D.Wu*, “Transfer Learning for Brain-Computer Interfaces: A Euclidean Space Data Alignment Approach,” IEEE Trans. on Biomedical Engineering, 26(2), pp. 399-410, 2020.

List of speakers

Dongrui Wu:

Dongrui Wu (IEEE Fellow) received a B.E in Automatic Control from the University of Science and Technology of China, Hefei, China, in 2003, an M.Eng in Electrical and Computer Engineering from the National University of Singapore in 2006, and a PhD in Electrical Engineering from the University of Southern California, Los Angeles, CA, in 2009. He is now Professor and Deputy Director of the Key Laboratory of the Ministry of Education for Image Processing and Intelligent Control, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China.

Prof. Wu's research interests include brain-computer interface, machine learning, computational intelligence, and affective computing. He has more than 200 publications (10000+ Google Scholar citations; h=54). He received the IEEE Computational Intelligence Society (CIS) Outstanding PhD Dissertation Award in 2012, the IEEE Transactions on Fuzzy Systems Outstanding Paper Award in 2014, the IEEE Systems, Man and Cybernetics (SMC) Society Early Career Award in 2017, the USERN Prize in Formal Sciences in 2020, the IEEE Transactions on Neural Systems and Rehabilitation Engineering Best Paper Award in 2021, the Chinese Association of Automation Early Career Award in 2021, and the Ministry of Education Young Scientist Award in 2022. His team won the First Prize of the China Brain-Computer Interface Competition in four successive years (2019-2022). Prof. Wu is the Editor-in-Chief of IEEE Transactions on Fuzzy Systems.

Siyang Li:

Siyang Li received a B.A. in Mathematics and Computer Science from New York University in 2019, an M.Sc. in Artificial Intelligence from Boston University in 2021. He is currently a Ph.D. student advised by Professor Dongrui Wu at School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China. Siyang's research interests include machine learning and its applications to brain-computer interface.