DECODING HUMAN BRAIN SIGNALS: A KNOWLEDGE DRIVEN APPROACH

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ABSTRACT

Brain-computer interface (BCI) decoding aims to develop algorithms that can map brain signals into commands to control external devices such as prosthetic limbs. Most of the existing decoding algorithms tend to be data-driven, ignoring related domain knowledge. As a result, they often lack robustness and accuracy when data is noisy or insufficient. More importantly, they cannot generalize well across subjects. To address these limitations, we propose to explicitly exploit the related neurological, physical, and anatomical knowledge and combine them with brain signals to achieve more accurate and generalizable brain decoding.

First, most features used by existing decoding models are defined by expertise. Their optimality for different BCI tasks is unknown. We propose an adaptive learning method that will automatically learn the best feature for each task. Evidence from the field of neuroscience suggests that the human brain is organized hierarchically. Our multi-layer deep learning structure, which we have termed smooth convolutional stacked auto-encoders (SCSA), takes advantage of this hierarchical design to automatically learn features from raw electrocorticography (ECoG) signals. The open architecture of SCSA allows for the incorporation of various domain-specific constraints, such as smoothness of the extracted features over time.

Secondly, the movement of an external device like a prosthetic limb is subject to physical and anatomical constraints which are often ignored by the existing decoding algorithms. We propose a Bayesian decoding model to explicitly capture the constraints and combine them with brain measurements, yielding a significant improvement in decoding accuracy. Specifically, we exploit the constraints that govern finger flexion and incorporate them into a prior model on finger movement. The improved finger flexion decoding is then achieved by combining the prior model with the ECoG signals.

Thirdly, existing decoding algorithms are difficult to generalize across trials or subjects. To address this problem, we introduce a new learning scheme, called learning with target prior. Learning with target prior uses generic knowledge about

the target variables rather than the exact labels to train the decoding algorithm. This improves the algorithm's ability to be generalized and reduces its reliance on labeled training samples. The method can also be extended to allow online updating of the decoding functions.

Fourthly, although the connections and dependencies among different parts of the brain play a critical role in brain function, they are seldom taken into account when decoding. We introduce the spatial temporal varying dynamic Bayesian network (STVDBN) to characterize the spatial and temporal functional dependencies, which are then used to construct decoding algorithms.

In conclusion, by explicitly exploiting and incorporating the related generic domain knowledge, we can improve BCI decoding performance regarding accuracy, robustness, and generalizability.