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Decoding Kinematic Characteristics of Finger Movement from Electrocorticography Using Classical Methods and Deep Convolutional Neural Networks

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Abstract : Brain-computer interfaces are a growing research field producing many implementations that find use in different fields and are used for research and practical purposes. Despite the popularity of the implementations using non-invasive neuroimaging methods, radical improvement of the state channel bandwidth and, thus, decoding accuracy is only possible by using invasive techniques. Electrocorticography (ECoG) is a minimally invasive neuroimaging method that provides highly informative brain activity signals, effective analysis of which requires the use of machine learning methods that are able to learn representations of complex patterns. Deep learning is a family of machine learning algorithms that allow learning representations of data with multiple levels of abstraction. This study explores the potential of deep learning approaches for ECoG processing, decoding movement intentions and the perception of proprioceptive information. To obtain synchronous recording of kinematic movement characteristics and corresponding electrical brain activity, a series of experiments were carried out, during which subjects performed finger movements at their own pace. Finger movements were recorded with a three-axis accelerometer, while ECoG was synchronously registered from the electrode strips that were implanted over the contralateral sensorimotor cortex. Then, multichannel ECoG signals were used to track finger movement trajectory characterized by accelerometer signal. This process was carried out both causally and non-causally, using different position of the ECoG data segment with respect to the accelerometer data stream. The recorded data was split into training and testing sets, containing continuous non-overlapping fragments of the multichannel ECoG. A deep convolutional neural network was implemented and trained, using 1-second segments of ECoG data from the training dataset as input. To assess the decoding accuracy, correlation coefficient r between the output of the model and the accelerometer readings was computed. After optimization of hyperparameters and training, the deep learning model allowed reasonably accurate causal decoding of finger movement with correlation coefficient $r = 0.8$. In contrast, the classical Wiener-filter like approach was able to achieve only 0.56 in the causal decoding mode. In the noncausal case, the traditional approach reached the accuracy of $r = 0.69$, which may be due to the presence of additional proprioceptive information. This result demonstrates that the deep neural network was able to effectively find a representation of the complex top-down information related to the actual movement rather than proprioception. The sensitivity analysis shows physiologically plausible pictures of the extent to which individual features (channel, wavelet subband) are utilized during the decoding procedure. In conclusion, the results of this study have demonstrated that a combination of a minimally invasive neuroimaging technique such as ECoG and advanced machine learning approaches allows decoding motion with high accuracy. Such setup provides means for control of devices with a large number of degrees of freedom as well as exploratory studies of the complex neural processes underlying movement execution.

Keywords : brain-computer interface, deep learning, ECoG, movement decoding, sensorimotor cortex
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