Brain Computer Interface – a New Challenge for Application of Inductive Modeling

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Abstract. The Brain Computer Interface (BCI) is a system which translates recordings of the brain’s neural activity into commands for external devices. For neuronal signal decoding, a model is adjusted to an individual brain during the BCI system learning (calibration). BCI control system identification represents an example of analysis of complex system having no definite theory. The specificity of the BCI tasks can be summarized as multi-way structure of data, high dimension, and variability. Methods of inductive modeling are particularly efficient for fast and efficient structural modeling. Brain computer interface represents a new challenging task for application of inductive modeling methods and algorithms.

Keywords
Brain computer interface, electrocorticographic signals, multi-way modeling, tensor data, dimension reduction, real-time application

The Brain Computer Interface (BCI) is a system which translates recordings of the brain’s neural activity into commands for external devices. Neural activity is registered using array/matrix of electrodes, invasively or noninvasively (Hochberg et al., 2012; Wolpaw and Wolpaw, 2012). For neuronal signal decoding, a model is adjusted to an individual brain during the BCI system learning (calibration). A decoder allows controlling an external effector (e.g. the fragments of exoskeletons) at the stage of the online execution. Identification of model for neuronal signal decoding is the crucial step of BCIs. The choice of the appropriate algorithm for model identification depends on the specificity of the problem to be solved. The specificity of the BCI tasks can be summarized as follows.

Multi-way structure of data. Several domains of analyses (temporal, frequency and spatial) are necessary for efficient decoding. Multi-way analysis was recently reported to be an efficient way to calibrate BCI systems by providing simultaneous signal processing in several domains. It represents a natural approach for modalities fusion and is based on the tensor data representation. Several tensor-based approaches have been recently invented and applied for BCI (Chao et al., 2010; Li and Zhang, 2010).

High dimension. Discrete or continuous output should be predicted from input variables extracted from neuronal activity recording. Multiple output variables represent external effector activation. Generally a large number of input variables are used. A part of them are irrelevant and highly correlated.

Variability. The variability of the neuronal signals, in particular, due to brain plasticity, requires recalibration of the BCI systems. In majority of BCI studies daily system recalibration is required. The full system recalibration is a time and labor-consuming procedure. Adaptive calibration aims to provide a fast adjustment of the BCI system in response to moderate changes of the signal.

Real time application. After the BCI system calibration, decoder should be applied in BCI experiments for neuronal signals processing in real-time. Thus, the computational efficiency of BCI systems is of crucial importance. Selecting the appropriate features subset is needed to optimize a computational efficiency and to improve quality of control.

A set of algorithms for BCI system calibration (Eliseyev et al., 2012a,b; Eliseyev and Aksenova, 2013) were developed at CEA/LETI/CLINATEC, Grenoble, France. CLINATEC® BCI project includes the realization of a fully implantable device, WIMAGINE®, to measure and transmit electrocorticographic (ECoG) signals wireless to a terminal.
(Charvet et al. 2012), and the means for a tetraplegic subject to pilot effectors, such as fragments of exoskeleton. The algorithms for BCI-CLINATEC system calibration are addressed to a data set of hugedimensions. They belong to the Partial Least Square (PLS) family (Geladiand Kowalski 1986) (Bro 1996) and properly treat data when matrices/tensors of observationscontain more variables than observations and variables are highly correlated. The method is based on matrix/tensor factoriztion and projection of the data onto the low dimensional space of latent variables. Recursive N-way PLS (Eliseyev and Aksenova, 2013) proved block-wisesingle pass BCI system calibration and can be applied online. L1-Penalized N-way PLS was proposed for subset of variables selection (Eliseyev et al., 2012b).

BCI control system identification represents an example of analysis of complex system having no definite theory. Methods of inductive modeling are particularly efficient for fast and efficient structural modeling from high dimensional data. Brain computer interface may represent a new challenging task for application of inductive modeling methods and algorithms.

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