Linear and Non-linear Decoding of Arm Trajectory from Electrocorticographic Recording of Motor Cortical Activity

Andrey Eliseyev and Tetiana Aksenova

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 control model is adjusted to an individual brain during the learning of the BCI system. The model allows the control of an external effector at the stage of the online execution. Multi-way analysis was recently reported to be an efficient way to calibrate BCI systems by providing simultaneous signal processing in several domains (temporal, frequency and spatial). In particular, the algorithms of Partial Least Squares (PLS) regression family were applied for continuous hand movement trajectory reconstruction from Electrocorticogram (ECoG) recordings [1-3]. PLS algorithms are particularly suited for high dimensional variables (more variables than observations), providing stable linear model. In the same time, non-linear non-Gaussian models, in particular Generalized Linear Models (GLM), relating hand kinematics with neural firing, show promising results for neural decoding [4].

Coupling of algorithms of PLS family with GLM allows considerable improvement of hand movement trajectory reconstruction from ECoG compared to linear modeling. Especially, the stability of reconstructed trajectories is enhanced. The publicly available data (http://neurotycho.org) were used for the comparison. The experiments are described in detailed in [2]. The feature tensor was formed following [2] using Continuous Wavelet Transform with frequency from 10 to 150, time step 100ms for all the electrodes (32 electrodes). The recording was randomly selected from the database. Algorithms were learned with 10 minutes and tested with rest 5 minutes of the recording. The algorithms of PLS family could be coupled with GLM (e.g., [5]). In the present paper, Unfolded PLS (UPLS), which was applied in original paper [2] to analyze the dataset, is compared with UPLS-GLM algorithm. Correlation coefficient R, normalized Absolute Mean Errors (AME), and normalized Absolute Mean Difference Errors (AMDE) were chosen as criteria of comparison. They were averaged over 10 randomly selected training datasets. Normalized AME characterizes the prediction errors by mean L1 distance between the real and the predicted trajectories related to the signal amplitude, whereas normalized AMDE shows the same distance for derivatives of trajectories.

PLS-GLM improves correlation R_{UPLS} = 0.61, 0.70, 0.75 (0.69 in average) vs. $R_{UPLS\text{-}GLM}$ = 0.68, 0.78, 0.79 (0.75 in average) for all the coordinates X, Y, Z. Moreover, it provides better AME and AMDE: AME_{UPLS} = 0.36, 0.29, 0.23 (0.29 in average) vs. $AME_{UPLS\text{-}GML}$= 0.33, 0.23, 0.16 (0.24 in average), $AMDE_{UPLS}$ = 1.06, 1.30, 1.08 (1.15 in average) vs. $AMDE_{UPLS\text{-}GLM}$ = 0.55, 0.43, 0.52 (0.50 in average). Thus, UPLS-GLM provides 9% of improvement for correlation, 17% of improvement for AME, and 57% of improvement for AMDE. As linear algorithm shows high level of errors in differences $AMDE_{UPLS}$ >1 (the level of errors is higher than amplitude of the original signal), non-linear GLM model provides more stable solution.

The PLS-GLM algorithm is currently used at CLINATEC (CEA, LETI) BCI platforms for preclinical and clinical studies.

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The authors are grateful to Prof. A.-L. Benabid, Drs. A. Wyss, C. Moro, N. Torres, T. Costecalde, G. Charvet, F. Sauter, J. Porcherot, A. Serpollet and C. Mestais, as well as to all members of the CEA, LETI, CLINATEC team. This work was partially supported by a non-restricted research grant from the Edmond J. Safra Philanthropic Foundation.

A. Eliseyev is with CEA, LETI, CLINATEC, MINATEC Campus, 17 rue des Martyrs, 38054 Grenoble Cédex, France (e-mail: andrey.eliseyev@gmail.com).

T. Aksenova is with CEA, LETI, CLINATEC, MINATEC Campus, 17 rue des Martyrs, 38054 Grenoble Cédex, France (corresponding author, phone: +33-438780320; fax: +33 4 38 78 54 56; e-mail: tetiana.aksenova@cea.fr).