연속적인 뇌파 분류를 위한 비음수 텐서 분해

이혜경° A. Cichocki 최승진
포항공과대학교 컴퓨터공학과, RIKEN BSI (Japan)
leehk@kiise.or.kr, a.cichocki@riken.jp, seungjin@postech.ac.kr

NONNEGATIVE TENSOR FACTORIZATION FOR CONTINUOUS EEG CLASSIFICATION

Hyekyoung Lee° A. Cichocki Seungjin Choi
POSTECH RIKEN BSI (Japan)

Brain computer interface (BCI) is a system that is designed to translate a subject's intention or mind into a control signal for a device such as a computer, a wheelchair, or a neuroprosthesis. BCI provides a new communication channel between human brain and computer and adds a new dimension to human computer interface (HCI). It was motivated by the hope of creating new communication channels for disabled persons, but recently draws attention in multimedia communication as well.

The most popular sensory signal used for BCI is electroencephalogram (EEG) which is the multivariate time series data where electrical potentials induced by brain activities are recorded in a scalp. Inferring the human intention using EEG is similar to inferring what is going on in a game from the hubbub outside a stadium. If a lot of people in the stadium shout simultaneously when a team scores a goal or loses a goal, we can guess the situation only just hearing hubbub outside the stadium, without being in the stadium. Stimuli make neurons to cheer in chorus, which makes EEG to have certain characteristics.

Exemplary spectral characteristics of EEG, in motor imagery tasks which are considered in this paper, are mu rhythm (8−12 Hz) and beta rhythm (18−25 Hz) which decrease during movement or in preparation for movement (event-related desynchronization, ERD) and increase after movement and in relaxation (event-related synchronization, ERS). However those phenomena could happen in different frequency bands, depending on subjects. For instance, they might occur in 16−20 Hz, not in 8−12 Hz.

EEG classification using ERD and ERS during motor imagery, has been extensively studied. Along this line, various methods have been developed with promising results. Besides motor imagery task, cognitive tasks has recently been studied in BCI community, including word generation, recall, expectancy, subtraction, and so on. Spectral properties related to cognition and perception are known to involve in the gamma band (30−100 Hz) at posterior and central scalp and to involve in the theta band (3−7 Hz) at bilateral and midline frontal scalp if they are also related with memory. However, such characteristics are not strongly distinguishable, compared to ERD and ERS. Moreover, their variations are very large depending on subjects. Therefore, methods for determining meaningful discriminative features become more important.

Linear data model is a widely-used method for multivariate data analysis, including principal component analysis (PCA), linear discriminant analysis (LDA), and independent component analysis

(ICA). Linear data model assumes that the observed multivariate data is represented by a weighted linear sum of basis vectors. Depending on criteria, different meaningful basis vectors are learned from data and appropriate features (corresponding to encoding variables) are determined by simply projecting data onto basis vectors. It was also shown in EEG analysis and classification.

Nonnegative matrix factorization (NMF) is another interesting linear data model, which is more appropriate for handling nonnegative data. In contrast to other linear data models, NMF allows only non-subtractive combinations of nonnegative basis vectors, providing a parts-based representation. The time-frequency representation of EEG data computed by short-time Fourier transform or wavelet transform, can be cast into a nonnegative data matrix. Recently, NMF was shown to be useful in determining discriminative basis vectors which well reflect meaningful spectral characteristics without the cross-validation in motor imagery EEG task.

Multiway analysis extends aforementioned linear methods, working with multiway data array which is referred to as tensor. PARAFAC and multiway SVD (higher-order SVD) are exemplary methods which are extensions of factor analysis and SVD. Recently PARAFAC model was exploited in EEG data analysis. Nonnegative tensor factorization (NTF) incorporates nonnegativity constraints into PARAFAC model, extending NMF in the framework of tensor algebra. Various information divergences were employed in NTF.

In this paper, we revisit PARAFAC model and present a NTF algorithm in a compact form, in the framework of tensor algebra. Then we cast the time-frequency representation of multichannel EEG data into a N-way tensor and apply NTF to determine discriminative spectral features. With these features, we use the Viterbi algorithm for continuous EEG classification with no trial structure. This is an extension of our previous work on the use of nonnegative matrix factorization (NMF) for EEG classification. Numerical experiments with two data sets in BCI competition, confirm the useful behavior of the method for continuous EEG classification.