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研究課題名（和文）Bayesian Tensor Models for Multiway Structural Data: A Theoretical Study and Applications

研究課題名（英文）Bayesian Tensor Models for Multiway Structural Data: A Theoretical Study and Applications

研究代表者

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研究成果の概要（和文）：本プロジェクトでは、テンソル因子分解の確率モデル及び脳波信号とコンピュータビジョン応用の研究を行っていた。1) 部分的に観測されたデータを用いて調整パラメーターなしでCPランクを自動的に推測し、外れ値を取り出すことが出来る。2) 潜在変数に対する平滑制約付きテンソル補完法を提案した。視覚データ処理に優れた。3) 勾配法による低ランク近似分解における効率的な非負タッカー分解算法を提案した。4) 非線形テンソル部分的最小二乗算法に基づくマルチブロックテンソルに対して回帰モデルを提案した。5)提案したテンソル算法による脳波アーチファクト、画像やビデオおよびMRIデータのノイズ除去を行った。

研究成果の概要（英文）：In this project, we study the probabilistic model of tensor factorizations and their applications to EEG signals and computer vision. 1) We proposed a Bayesian robust CP tensor factorization with missing data, which can infer automatically the underlying CP rank and capture outliers effectively from partially observed data without tuning parameters. 2) We proposed a tensor completion method with smoothness constraints over latent factors, which is particularly useful for visual data. 3) We proposed an efficient algorithm for non-negative Tucker decomposition by employing low-rank approximations of the gradient. 4) We proposed a nonlinear tensor partial least squares algorithm for multi-block tensor regression. 5) We applied our proposed methods to EEG artifact removal, image/video denoisiong, and MRI denoising.

研究分野： 情報学

キーワード： Tensor Factorization　Missing Data　Tensor Completion　Robust Factorization

１．研究開始当初の背景

Tensors (multiway arrays) provide a faithful and efficient way to represent the multi-dimensional structure data or datasets affected by multiple factors. Tensor factorizations enable us to explicitly take into account the structure dependency within the data and effectively capture the underlying multiple sets of factors. In recent years, tensor models for multiway data are becoming attractive in various applications such as multilinear feature extraction and data completion. However, probabilistic models for tensor analysis are not widely explored and the uncertainty of latent factors are not considered in the existing methods. Furthermore, the determination of CP rank remains a challenging problem. The robust tensor factorizations with missing data are also challenging problems.

２．研究の目的

This project mainly focuses on several objectives:

(1)　We study fundamental theory, model and inference algorithms for Bayesian probabilistic tensor factorizations, resulting in a breakthrough for multiway structural data processing.

(2)　We study the probabilistic model for tensor decompositions with missing data and outliers. Based on the partially observed tensor data, the model aims to predict missing data with high accuracy. In addition, the outliers or non-Gaussian noise can be captured explicitly, which leads to a robust tensor factorization method.

(3)　We study the automatic CP rank determination problem by employing group sparsity priors on factor matrices. The key concept is to infer the lowest rank for given observed data under CP model.

(4)　We investigate the potential applications of Bayesian tensor factorizations, especially for EEG signal processing and image and video analysis.

３．研究の方法

(1)　We formulate tensor factorization model by using probabilistic method, which can take into account the uncertainty of latent factors.

(2)　To capture outliers, the sparse priors are applied to each individual element of the tensor.

(3)　To automatic learn the CP rank of a partially observed tensor, we employ hierarchical sparsity priors over each column of latent factors, i.e., group sparsity prior. Based on this setting, the method can infer low-rank latent factors with minimal component of rank-one tensor.

(4)　To learn the model, we develop an efficient variational Bayesian inference method to compute approximate posteriors of all unknown variables.

(5)　We apply our proposed Bayesian tensor factorization and Bayesian robust tensor factorization methods to various applications. One application is to employ Bayesian tensor completion for EEG artifact removal. Another application is to separate background and foreground of videos by using Bayesian robust tensor factorization. In addition, our method has been successfully used for image, video and MRI denoising.

４．研究成果

(1)　We propose a generative model for robust tensor factorization in the presence of both missing data and outliers. The objective is to explicitly infer the underlying low-CP-rank tensor capturing the global information and a sparse tensor capturing the local information (also considered as outliers), thus providing the robust predictive distribution over missing entries. Our method can perform model selection automatically and implicitly without the need of tuning parameters. More specifically, it can discover the ground-truth of CP rank and automatically adapt the sparsity inducing priors to various types of outliers. In addition, the tradeoff between the low-rank approximation and the sparse representation can be optimized in the sense of maximum model evidence. The advantages of our method have been demonstrated by video background modeling and image denoising.

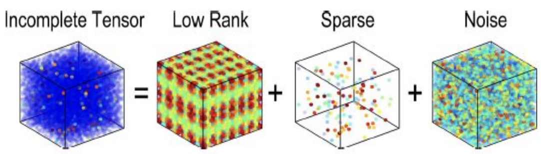

Fig.1 Bayesian robust tensor factorization

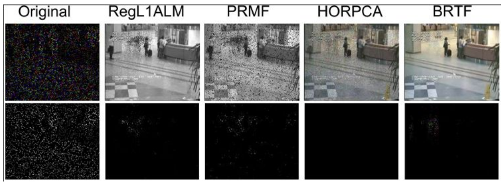

Fig.2 Background modeling when 90% pixels are missing. Our method BRTF outperforms other existing methods.

(2) High accuracy of EEG classification can hardly be achieved if the signals are contaminated by severe artefacts. We consider a more elegant way that tries to recover the disturbed segments from other undisturbed segments. The possible artefacts in EEG are treated as missing values, then the Bayesian tensor factorization based method is employed to implement EEG completion for artefact removal. Therefore, the EEG missing values are effectively predicted with robustness to overfitting. The effectiveness is demonstrated by brain computer interface applications.

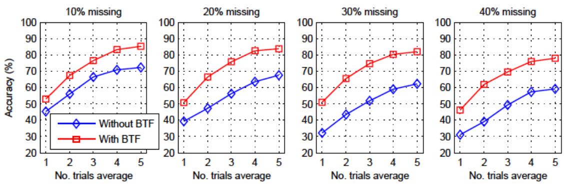

Fig. 3 The classification accuracy of EEG data by using BTF and without using BTF.

(3) We propose a tensor based non-local filtering technique for image denoising using Bayesian CP factorization. Our method can learn CP-rank as well as noise variance solely from the observed noisy tensor data, which can also avoid overfitting problem. The experimental results on image and MRI denoising demonstrate the superiorities of our method in terms of flexibility and performance.

Table 1 The denoising performance (PSNR) for MRI data.

	Noise standard deviation		
Methods	5%	10%	15%
BCPF	36.98 dB	36.05 dB	32.99 dB
HOSVD	27.33 dB	22.60 dB	19.97 dB

(4) We propose an efficient algorithm for performing tensor completion that is particularly powerful regarding visual data. The concept is to impose the smoothness constraints to the latent factors while performing low-rank CP factorization. To this end, we employ total variation and quadratic variation strategies and invoke the corresponding algorithms for model learning. The experimental results on visual data illustrate the significant improvements of our method.

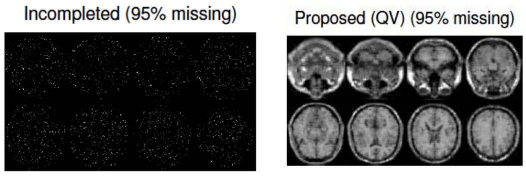

Fig. 4 Tensor completion for MRI data with 95% missing values.

(5) The existing nonnegative Tucker decomposition (NTD) suffer from a very high computational complexity in terms of both storage and computation time, which has been one major obstacle for practical applications. To overcome these disadvantages, we show how multilinear rank approximation of tensors is able to significantly simplify the computation of the gradients of the cost function, upon which a family of efficient first-order NTD algorithms are developed. Therefore, the new algorithm can dramatically reduce the storage complexity and running time.

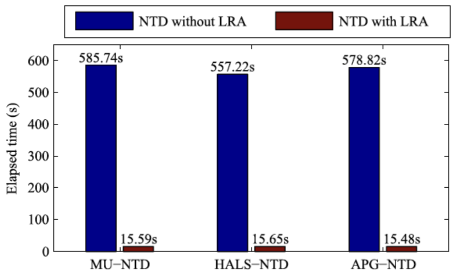

Fig. 5 Comparison of runtime between the NTD algorithms with or without low-ran approximation.

(6) We introduce a new generalized nonlinear tensor regression framework called kernel-based multiblock tensor partial least squares (KMTPLS) for predicting a set of dependent tensor blocks from a set of independent tensor blocks through the extraction of a small number of common and discriminative latent components. By considering both common and discriminative features, KMTPLS effectively fuses the information from multiple tensorial data sources and unifies the signal and multiblock tensor regression scenarios into one general model. An efficient learning algorithm for

KMTPLS based on sequentially extracting common and discriminative latent vectors is also developed. The effectiveness of our method is demonstrated by reconstruction of human pose from multiview video sequences.

５．主な発表論文等
（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計 6 件）

① G. Zhou, Q. Zhao, Y. Zhang, T. Adali, S. Xie, A. Cichocki, "Linked component analysis from matrices to high-order tensors: applications to biomedical data", *Proceedings of the IEEE*, Vol.104, pp.310-331, 2016, refereed
DOI: 10.1109/JPROC.2015.2474704

② Y. Zhang, G. Zhou, J. Jin, Q. Zhao, X. Wang, A. Cichocki, "Sparse Bayesian classification of EEG for brain computer interface", *IEEE Transactions on Neural Networks and Learning Systems*, vol. 27, pp.2256-2267, 2016, refereed
DOI: 10.1109/TNNLS.2015.2476656

③ T. Yokota, Q. Zhao, A. Cichocki, "Smooth PARAFAC decomposition for tensor completion", *IEEE Transactions on Signal Processing*, vol. 64, pp. 5423-5436, 2016, refereed
DOI: 10.1109/TSP.2016.2586759

④ Q. Zhao, G. Zhou, L. Zhang, A. Cichocki, "Bayesian robust tensor factorization for incomplete multiway data", *IEEE Transactions on Neural Networks and Learning Systems*, vol. 27, pp. 736-748, 2016, refereed
DOI: 10.1109/TNNLS.2015.2423694

⑤ Y. Liu, Q. Zhao, L. Zhang, "Uncorrelated multiway discriminant analysis for motor imagery EEG classification", *International Journal of Neural Systems*, vol. 25, pp. 1550013(14), 2015, refereed
DOI: http://dx.doi.org/10.1142/S0129065715500136

⑥ G. Zhou, A. Cichocki, Q. Zhao, S. Xie, "Efficient nonnegative Tucker decompositions: Algorithms and uniqueness", *IEEE Transactions on Image Processing*, vol. 24, pp.4990-5003, 2015, refereed
DOI: 10.1109/TIP.2015.2478396

〔学会発表〕（計 4 件）

① G. Lihua, G. Cui, Q. Zhao, D. Wang, A. Cichocki, J. Cao, "Video denoising using low rank tensor decomposition", *Proceedings of 9th International Conference on Machine Vision*, Nov.18-20th, 2016, Nice, France.

② L. Gui, Q. Zhao, J. Cao, "Tensor denoising using Bayesian CP factorization", *The 6th International Conference on Information Science and Technology*, May 6-8th, 2016, Dalian, China.

③ Y. Zhang, Q. Zhao, G. Zhou, J. Jin, X. Wang, A. Cichocki, "EEG completion via Bayesian tensor factorization for brain computer interface", *IEEE International conference on Acoustics, Speech and Signal Processing (ICASSP),* Mar. 20-25th, 2016, Shanghai, China.

④ M. Hou, Q. Zhao, B. Draa, A. Cichocki, "Common and discriminative subspace kernel-based multiblock tensor partial least squares regression", *Proceedings of the 30th AAAI conference on Artificial Intelligence*, Feb. 12-17th, 2016, Arizona, USA.

〔図書〕（計 0 件）

〔産業財産権〕

○出願状況（計 0 件）

名称：
発明者：
権利者：
種類：
番号：
出願年月日：
国内外の別：

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名称：
発明者：
権利者：
種類：

番号：
取得年月日：
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〔その他〕
ホームページ等

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