The Power of Tensor-Based Approaches for ECG Signal Processing

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Abstract—**This paper gives an overview of different applications where tensors have been used to solve problems in cardiac processing. We show that tensor-based methods are very suitable to represent data with multiple modes, and lead to improved results compared to matrix-based methods when multiple leads need to be processed simultaneously.**

I. Introduction

When multiple leads in Electrocardiography (ECG) are present, most methods process each lead individually and combine decisions from all leads in a later stage. While this approach is popular, it fails to exploit the structural information captured by the different leads. Tensor-based methods represent the signals by tensors, which are higher-order generalizations of vectors and matrices that allow the analysis of multiple modes simultaneously. In this paper, we apply a technique called *segmentation* to a multilead ECG data matrix, obtaining a third-order tensor with modes *channels*×*time*×*beats*. and focus on the canonical polyadic decomposition (CPD) and multilinear singular value decomposition (MLSVD) which have become popular tools in biomedical signal processing in recent years.

II. Methods

CPD and MLSVD are respectively the multilinear generalization of the dyadic decomposition and the singular value decomposition (SVD) for matrices [1]. CPD uniqueness can be proven under mild conditions, facilitating the physiological interpretation of the factors. MLSVD and multilinear PCA allow a mode-dependent compression rate, tailored to the data characteristics. These are major strengths.

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III. Results

To tensorize ECG signals in T-wave alternans detection, the T waves are segmented beat-by-beat and stacked slice-wise in a third-order tensor [2]. A similar tensorization approach has been applied to abnormal heartbeat detection using CPDs and linear systems with constrained CPD solution, leading to sensitivity and specificity results above 90%. A similar approach has been used to detect atrial fibrillation in single- and multilead ECG signals [2]. Additionally, a weighted CPD variant, which enables us to incorporate prior knowledge about the signal quality, has been applied to analyze changes in heartbeat morphology prior to in-hospital cardiac arrest in three different patient groups. Their potential to identify patients at risk is shown [2].

Further extending the abnormal heartbeat detection problem, MLSVD is applied to classify four types of heartbeat classes (including normal) from 12-lead ECG data. To characterize the morphological variations of different types of heartbeats, a multiscale analysis using discrete wavelet transform is adopted where an ECG heartbeat is decomposed into different subbands [3]. The decomposed subbands of each lead are juxtaposed slice-wise in a third-order tensor. As such, this tensor-based approach fully exploits the intra-beat, interbeat and interlead correlations simultaneously, resulting in Sensitivity (S) and Positive predictive value (P^+) above 95% for normal and ventricular beats, whereas for supraventricular beats the S and P+ results are above 87% and 85%, respectively.

IV. Discussion & Conclusion

This paper shows the power of tensor decompositions for different ECG applications such as data compression, heartbeat classification, myocardial infarction classification, T-wave alternans analysis, and analysis of changes in heart beat morphology prior to in-hospital cardiac arrest. We conclude that tensor-based methods are very suitable and highly flexible to represent data with multiple modes, and outperform their matrix-based counterparts when multiple leads need to be processed simultaneously.

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