Chapter 9

Two-Directional Two-Dimensional Principal Component Analysis Based on Wavelet Decomposition for High-Dimensional Biomedical Signals Classification

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ABSTRACT

Here, we present a multi-scale two-directional two-dimensional principal component analysis (MS2D^{2}PCA) method for the efficient and effective extraction of essential feature information from signals. Time-invariant multi-scale matrices are constructed in the first step. The two-directional two-dimensional principal component analysis then operates on the multi-scale matrices to reduce the dimension, rather than vectors in conventional PCA. Results are presented from an experiment to classify twenty hand motions using 89-channel EMG signals recorded in stroke survivors, which illustrates the efficiency and effectiveness of the proposed method for biomedical signal analysis. With this multi-scale two-directional two-dimensional principal component analysis for high-dimensional signal classification, spatial-time-frequency discriminant information from high-dimensional EMG electrode array can be effectively extracted and reduced using the proposed method. Compared with the time domain feature extraction in conjunction with PCA, MS2D^{2}PCA performed better with higher classification accuracy and less PCs in EMG classification. The efficiency and effectiveness of the method can be further validated by using high-dimensional EEG, MEG, fMRI signals. Although the present study focuses on high-dimensional signal pattern classification, based on the PCs obtained at multiple scales, it is relatively straightforward to expand MS2D^{2}PCA for high-dimensional signal compression, denoising, component extraction, and other related tasks.

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INTRODUCTION AND BACKGROUND

Most biomedical signals are typically non-linear and non-stationary. Time-frequency (TF) analysis including the wavelet transform (WT), offers simultaneous interpretation of the biomedical signal in both the time and frequency domains, allowing the elucidation of local, transient or intermittent components at various scales (Xie, Zheng, & Guo, 2009). However, there are typically a large amount of wavelet coefficients generated from such a two-dimensional analysis. In addition, noise artifacts as well as redundant information may be present in these time-frequency coefficients. Principal component analysis (PCA) decomposes the covariant structure of the dependent variables into orthogonal components by calculating the eigenvalues and eigenvectors of the data covariance matrix. It linearly projects the original data from a high-dimensional space to a set of uncorrelated components in a low-dimensional feature space, while simultaneously preserving the most original information. Therefore, WT combined with PCA (WT-PCA) has been one of the most powerful approaches for simultaneously extracting discriminative features and reducing the dimension for biosignals classification tasks. The basic algorithm for this hybrid method consists of decomposing biomedical signals into the time-frequency plane, re-arranging the time-frequency elements into a row vector, and reducing the dimension using PCA. Examples of application of this algorithm in the area of electromyographic (EMG) signal analysis include Englehart et al. (Chan, Englehart, Hudgins, & Lovely, 2001; Engelhart, Hudgins, Parker, & Stevenson, 1999), who decomposed four channels of transient EMG signals using short-time Fourier transform (STFT), WT, and wavelet packet transform (WPT) methods to discriminate six hand motions for prosthetic hand control. They compared the performance of PCA feature reduction against the Euclidean distance class separability (CS) criterion. The results indicated TF-PCA was vastly superior to TF-CS in classification accuracy, as well as a significant improvement of all TF-based methods compared to time domain feature extraction when using a linear discriminant analysis (LDA) classifier. The study of Khezri and Jahed (Khezri & Jahed, 2007) using adaptive neuro-fuzzy inference system further confirmed the superiority of TF-PCA hybridization in EMG-based hand motion pattern recognition. Chan et al. (Chan et al., 2001) performed a comparative study to identify acoustic words from ‘one’ to ‘nine’ from facial EMG signals. They found similar effectiveness and applicability of TF-PCA methods in speech recognition, especially WT-PCA. Chu et al. (Chu, Moon, & Mun, 2006) improved the TF-PCA technique by employing a self-organizing feature map (SOFM) to transform PCA-reduced TF features into a new feature space with high class separability. Kiatpanichagij and Afzulpurkar (Kiatpanichagij & Afzulpurkar, 2009) inserted an entropy-based supervised discretization procedure between the WPT and PCA steps to improve EMG classifier generalization and training speed on overlapping segmented signals. Qi et al. (Qi, Wakeling, Green, Lambrecht, & Ferguson-Pell, 2011) utilized the principal components of EMG intensity spectra obtained from non-linearly-scaled wavelets to compare motor unit recruitment patterns during isometric ramp and step muscle contractions, as well as dynamic concentric and eccentric contractions of the human biceps brachii. The same WT-PCA scheme was also employed to discriminate between fast and slow muscle fibers (Von Tscharner & Goepfert, 2006), investigate motor unit recruitment patterns between and within muscles of the triceps muscles (J. M. Wakeling, Uehli, & Rozitis, 2006), as well as quantify dynamic muscle dysfunction in children and young adults with cerebral palsy (J. Wakeling, Delaney, & Dudkiewicz, 2007). Weiderpass et al. (Weiderpass et al., 2013) investigated the alternations of thigh and calf muscles recruitment strategies during gait among non-diabetic and diabetic neuropathic patients by using an adaptive optimal kernel time-frequency representation and discrete WT followed by PCA.