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Multi-subregion based correlation filter bank for robust face recognition

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ABSTRACT

In this paper, we propose an effective feature extraction algorithm, called Multi-Subregion based Correlation Filter Bank (MS-CFB), for robust face recognition. MS-CFB combines the benefits of global-based and local-based feature extraction algorithms, where multiple correlation filters corresponding to different face subregions are jointly designed to optimize the overall correlation outputs. Furthermore, we reduce the computational complexity of MS-CFB by designing the correlation filter bank in the spatial domain and improve its generalization capability by capitalizing on the unconstrained form during the filter bank design process. MS-CFB not only takes the differences among face subregions into account, but also effectively exploits the discriminative information in face subregions. Experimental results on various public face databases demonstrate that the proposed algorithm provides a better feature representation for classification and achieves higher recognition rates compared with several state-of-the-art algorithms.

1. Introduction

In the past few decades, we have witnessed a rapid development of the theories and algorithms of face recognition and its successful applications in access control, video surveillance, law enforcement, human computer interaction, and so on [1–3]. However, face recognition is still a very challenging task due to large face appearance variations caused by occlusions, aging, changes of illumination, facial expression, pose, etc. In particular, in many real-world applications, it often suffers from the small sample size (SSS) problem [2] since the training samples of each subject are very few, which can severely affect the performance of most face recognition algorithms especially when the dimension of facial feature space is high.

It has been well recognized that effective feature extraction (FE) plays an important role in the success of a face recognition algorithm [1–4]. After the FE process, a proper low-dimensional feature vector, with which the class separability is enhanced and the computational complexity of subsequent classifiers is reduced, is generated. FE algorithms can be roughly grouped into two categories [4]: global-based and local-based. Global-based FE algorithms consider a face region as a whole. The extracted features contain the information embedded in the whole face [5]. On the other hand, local-based FE algorithms are based on face subregions (i.e., local facial features, such as eyes, nose, mouth, and chin [4,6,7]) and encode the detailed characteristics within each face subregion.

Traditional local-based FE algorithms usually combine the outputs from different face subregions by adopting a fusion strategy (e.g., the majority voting [8], the weighted sum [4,9,10], or the concatenation of original/low-dimensional features [11–13]). Note that the above-mentioned algorithms consider the local FE step and the combination of different subregions as two independent processes. Although many successful local-based FE algorithms have been proposed, how to combine these two processes as a whole remains an open issue.

In this paper, we propose an effective feature extraction algorithm, called Multi-Subregion based Correlation Filter Bank (MS-CFB), for robust face recognition. A new type of filter bank, i.e., Correlation Filter Bank (CFB), is employed in MS-CFB. We formulate the filter bank design as a minimization problem of the generalized Rayleigh quotient [14], which has a closed-form solution. The advantages of this development are the reduction in the computational complexity and the simplification in the decision process, since we can obtain multiple correlation filters corresponding to different face subregions simultaneously.

Compared with traditional algorithms, the proposed MS-CFB algorithm has the following characteristics:

- MS-CFB makes use of local facial features to perform global FE. Therefore, MS-CFB exploits the benefits of both local face

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subregions and the whole face for extracting features, which incorporates the advantages of both global-based and local-based FE algorithms.

- Traditional local-based FE algorithms consider the local FE step and the combination of different face subregions as two independent processes. In contrast, MS-CFB tries to unify these two processes in an integrated framework. The local FE step of MS-CFB aims to optimize the overall correlation outputs from all face subregions. Such strategy enhances the effectiveness of local feature extraction.
- While conventional correlation filters [15] rely on the frequency domain representations, the design process of a CFB is based on the spatial domain representations, which effectively reduces the computational complexity during the filter bank design process (this is because the Fourier transforms used in traditional algorithms are not required). Moreover, compared with commonly used constrained correlation filters in face recognition (such as OTF [15]), a CFB is designed by capitalizing on the unconstrained form to improve its generalization capability.

The remainder of this paper is organized as follows. Related work is discussed in Section 2. A detailed description of the proposed MS-CFB algorithm is presented in Section 3. In Section 4, the experimental results on various public face databases are given. Finally, the concluding remarks and future work are provided in Section 5.

2. Related work

In this section, we begin with reviewing some widely used FE algorithms including popular global-based and local-based FE algorithms in Section 2.1. Some traditional and recently developed correlation filters are described in Section 2.2. The motivation of this work is given in Section 2.3.

2.1. Global-based and local-based FE algorithms

A large number of global-based FE algorithms have been developed so far. One of the most successful algorithms for face recognition is appearance-based algorithms, where a face is represented as a vector (e.g., it can be obtained by concatenating each row/column of a face image) [5,16,17] or a tensor [18,19]. In practice, however, a high-dimensional vector or a tensor is too large to allow fast and robust face recognition. A common way to solve this problem is to use dimensionality reduction algorithms, such as Principal Component Analysis (PCA) [5], Linear Discriminant Analysis (LDA) [16,18], or Class-dependence Feature Analysis (CFA) [20,21,52]. Each projection vector in the projection matrix obtained by PCA (or LDA) tries to represent (or discriminate) all classes in the new feature space. On the other hand, each projection vector obtained by CFA, which is based on the design of the correlation filters, discriminates one class from all the other classes. Fig. 1 shows a comparison of the projection vectors obtained by LDA and CFA for a three-class problem.

Global-based FE algorithms, however, do not consider the diversity of local facial structures which can be useful for classification. Recently, local-based FE algorithms have received much attention due to the fact that local facial features (such as eyes and mouth) are more robust to variations of illumination, facial expression, and pose. In [22], the Local Feature Analysis (LFA) algorithm was introduced to encode the local topographic representations of a face image, where kernels of local spatial support are used to extract information from local face subregions. Kim et al. [11] presented a component-based LDA FE algorithm for image retrieval. Each face subregion is firstly represented as the LDA coefficients in the Fisher subspace. Then, a feature vector is formulated by concatenating all of the coefficients. Finally, a holistic LDA [16], which reduces the dimension of the combined feature vectors, is employed to obtain a compact representation. Li et al. [13] proposed a Block-based Bag Of Words (BBOW) algorithm for robust face recognition. Dense SIFT features [23] are calculated and quantized into different codewords for each face subregion. Then, histograms of each face subregion are concatenated to obtain a feature vector. Finally, linear SVM classifiers are employed to perform classification. Su et al. [4] proposed a novel face recognition algorithm which employs both global and local classifiers. The global feature vector is extracted from a whole face image by using the low frequency Fourier coefficients, while the local feature vector is constructed based on LDA. The final classifier is formed by combining (i.e., using the linear weighted sum) a global feature based classifier and a local feature based classifier. Zhu et al. [8] proposed a Patch-based Collaborative Representation based Classification (PCRC) algorithm for face recognition. The majority voting of the classification outputs from all face subregions is employed to make a final decision. Furthermore, in order to make PCRC less sensitive to the size of face subregions,

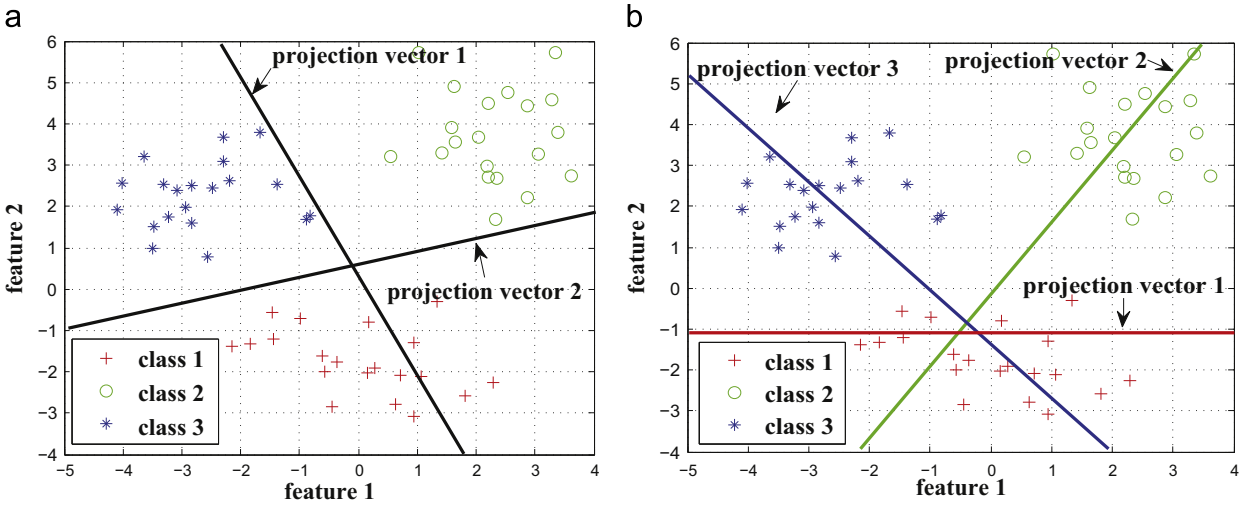

Fig. 1. A comparison of the projection vectors obtained by (a) LDA and (b) CFA for a three-class problem. Each projection vector obtained by LDA discriminates all three classes while that obtained by CFA discriminates one class from the other two classes. Note that LDA obtains only two projection vectors.

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