Information Sciences 375 (2017) 171–182

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Sample diversity, representation effectiveness and robust dictionary learning for face recognition

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ARTICLE INFO

Article history:
Received 27 September 2015
Revised 19 September 2016
Accepted 27 September 2016
Available online 28 September 2016

Keyword:
Dictionary learning
Sparse coding
Face recognition

ABSTRACT

Conventional dictionary learning algorithms suffer from the following problems when applied to face recognition. First, since in most face recognition applications there are only a limited number of original training samples, it is difficult to obtain a reliable dictionary with a large number of atoms from these samples. Second, because the face images of the same person vary with facial poses and expressions as well as illumination conditions, it is difficult to obtain a robust dictionary for face recognition. Thus, obtaining a robust and reliable dictionary is a crucial key to improve the performance of dictionary learning algorithms for face recognition. In this paper, we propose a novel dictionary learning framework to achieve this. The proposed algorithm framework takes training sample diversities of the same face image into account and tries to obtain more effective representations of face images and a more robust dictionary. It first produces virtual face images and then designs an elaborate objective function. Based on this objective function, we obtain a mathematically tractable and computationally efficient algorithm to generate a robust dictionary. Experimental results demonstrate that the proposed algorithm framework outperforms some previous state-of-the-art dictionary learning and sparse coding algorithms in face recognition. Moreover, the proposed algorithm framework can also be applied to other pattern classification tasks.

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1. Introduction

Dictionary learning is an important branch of sparse representation, and it is widely used in pattern recognition [13,47] and image processing [41]. Sparse representation has the key idea that samples can be sparsely represented by a large number of "atoms", and it is widely used for face recognition [35,43]. In order to produce competent "atoms", researchers have proposed various dictionary learning algorithms [5,45].

Although dictionary learning has exhibited promising performance in face recognition [4,5,12,44,45], previous dictionary learning algorithms suffer from the following problems. First, face recognition is a typical small sample size problem, and insufficient available samples have severe negative effects on dictionary learning algorithms for face recognition. Actually,

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http://dx.doi.org/10.1016/j.ins.2016.09.059
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learning an over-complete dictionary from just a limited number of high-dimensional images is a challenge for all image classification issues. Second, because the face images of the same person vary with facial poses and expressions as well as illumination conditions, it is hard to obtain a very robust dictionary for face recognition. For face recognition tasks, even if the dictionary is not very sensitive to variations in poses, expressions, and illumination conditions, it is able to obtain relatively stable descriptions of the face image with a high accuracy. Exploring and tackling the above two problems represent a significant step in the study of dictionary learning for face recognition. In order to achieve robust face recognition performance via dictionary learning, researchers have proposed novel algorithms with valuable ideas. For example, learning an "occlusion dictionary" is proposed for better recognition of occluded face images [19,44]. However, it seems that an "occlusion dictionary" is just a special-problem-associated algorithm and cannot perform very well when one is dealing with a general face recognition issue. Learning a robust dictionary [14] is also very important for other fields such as background modeling [25] and tracking [34]. In addition, dictionary learning has been applied to a wide array of image-associated tasks [17,24].

This paper proposes a new dictionary learning framework, focusing on enhancing the diversity of training samples of the same face and obtaining more effective representation of face images. The robust dictionary learning framework designed in this study is not only applicable to face recognition but can also be applied to other pattern classification tasks. For face recognition tasks, the proposed algorithm framework achieves robustness by exploiting an elaborated algorithm and by generating virtual face images that convey new possible poses and illuminations of the face. For other pattern classification tasks, the designed framework can be applied with either of the two following schemes. (1) Virtual training samples are first obtained by corrupting original training samples. Then the designed elaborated algorithm is applied to the original and virtual training samples. (2) The set of original training samples is divided into two, and the designed elaborated algorithm is applied to these two halves. In other words, the first and second halves are viewed as the original and virtual training samples, respectively. This scheme may be highly effective when there is a large number of original training samples. In particular, compared with previous robust dictionary learning algorithms on the basis of l_1 regularization such as those in [25,34], the elaborated algorithm designed in this paper has a much lower computational cost.

The remainder of this paper is organized as follows. Section 2 presents the related work of dictionary learning algorithms. Section 3 provides the proposed algorithm framework. Section 4 supplies the experimental results and analysis. Section 5 presents the conclusion.

2. Related work

Dictionary learning algorithms can be roughly categorized into three types: supervised dictionary learning algorithms, semi-supervised dictionary learning algorithms and unsupervised dictionary learning algorithms.

2.1. Supervised dictionary learning algorithms

Supervised dictionary learning algorithms are mainly designed based on the reconstruction error and constraint on labels. Dictionaries obtained in a supervised manner usually have strong discriminative power, and they have the potential to achieve excellent classification performance for classification problems. Studies on supervised dictionary learning have been extensively performed [7,10,21,31,32,40,42,46]. In order to improve the discriminative ability of the dictionary, the Fisher discrimination criterion [42] was used to implement the supervision. Moreover, Wang et al. [32] proposed learning class-specific dictionaries and a global dictionary shared by all categories. However, if the number of categories is large, the global dictionary may be not suitable for dealing with the complex category correlation. Zhang and Li [45] proposed the discriminative K-SVD algorithm (D-KSVD) based on the classification error. Jiang et al. [10] proposed the label consistent K-SVD algorithm (LC-KSVD) by constructing the discriminative sparse code error term to improve the discriminative ability of the learned dictionary. Recently, Cai et al. [5] proposed a support vector-guided dictionary learning algorithm (SVGDL) for image classification by using the weighted summation of the squared distances between all pairs of coding vectors to construct the discrimination term. Gu et al. [7] proposed a projective dictionary pair learning algorithm (PDPL) for pattern classification. Yang et al. [40] presented a unified model by integrating the analysis-synthesis dictionary learning and universality-particularity representation. Tang et al. [31] proposed an efficient method to learn a compact and discriminative dictionary for visual categorization, in which dictionary learning was formulated as a problem of graph partition. When dealing with high-complexity data due to the use of simple supervised techniques, many dictionary learning algorithms usually suffer from insufficient discrimination. Quan et al. [21] proposed a supervised dictionary learning algorithm by integrating multiple classifier training into dictionary learning to improve the discrimination. Moreover, in order to transform a dictionary learned from one visual domain to the other, Zhu and Shao [46] utilized weakly labeled data from other visual domains as the auxiliary source data for enhancing the original learning system. These supervised dictionary learning algorithms have achieved excellent performance in classification tasks. However, in many pattern classification problems, accessibility to a large set of labeled data may not be possible because labeling data is expensive and very time consuming. Thus, insufficient labeled training data are adverse to supervised dictionary learning algorithms.

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