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Kernel sparse representation with pixel-level and region-level local feature kernels for face recognition

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ABSTRACT

Face recognition has been popular in the pattern recognition field for decades, but it is still a difficult problem due to the various image distortions. Recently, sparse representation based classification (SRC) was proposed as a novel image classification approach, which is very effective with sufficient training samples for each class. However, the performance drops when the number of training samples is limited. In this paper, we show that effective local image features and appropriate nonlinear kernels are needed in deriving a better classification method based on sparse representation. Thus, we propose a novel kernel SRC framework and utilize effective local image features in this framework for robust face recognition. First, we present a kernel coordinate descent (KCD) algorithm for the LASSO problem in the kernel space, and we successfully integrate it in the SRC framework (called KCD-SRC) for face recognition. Second, we employ local image features and develop both pixel-level and region-level kernels for KCD-SRC based face recognition, making it discriminative and robust against illumination variations and occlusions. Extensive experiments are conducted on three public face databases (Extended YaleB, CMU-PIE and AR) under illumination variations, noise corruptions, continuous occlusions, and registration errors, demonstrating excellent performances of the KCD-SRC algorithm combining with the proposed kernels.

1. Introduction

Face recognition is an important research area in computer vision. It has many useful applications in real life, such as face attendance, access control, security surveillance, etc. Face recognition is also a challenging problem, which suffers from aging, occlusion, and intra-personal variations with pose, illumination, and expression. Many researchers have been attracted to solve these problems, making a great development in face recognition techniques during the past two decades.

Recently, Wright et al. proposed the sparse representation based classification (SRC) framework for robust face recognition [1], which makes use of the well-known ℓ_1-norm constrained least-square reconstruction technique (LASSO) [2]. In their work image pixel values are used to represent faces. The training set needs to be carefully constructed, that is, each subject in the training set is constituted with many images representing various lighting conditions. Thus a probe image of certain illumination condition can be represented by a sparse linear combination of the training samples. However, in realistic applications it is hard for every enrolled user to have such varying lighting images. When the number of available images per subject is limited, the linear SRC method may have difficulty in learning the correct representation. Fig. 1 shows an example where the linear SRC method (denoted as Pixel Linear) fails to identify a probe face image with severe illumination changes, when only five images per subject are available in the gallery.

The basic assumption in the original SRC algorithm is that the probe image can be linearly represented by gallery images of the same class. However, this assumption is hard to hold in difficult scenarios, for example, illumination variations and occlusions may be present in the probe face image but meanwhile the gallery may have small sample size. Therefore, nonlinear features and nonlinear kernels are needed to deal with difficult face recognition problems. Yuan and Yan [3], Min and Dugelay [4], and Chan and Kittler [5] proposed to utilize the Local Binary Pattern (LBP) descriptor [6] in the SRC framework, so that the system would be more robust against illumination variations, making it potentially possible to apply SRC for small-sample-size face recognition problem.

The LBP descriptor was originally proposed by Ojala et al. for texture classification [6]. It is a binary string (often converted to the corresponding decimal number as a label) resulted from local neighboring pixel comparisons. Ahonen et al. have applied LBP to face recognition and proved that it is robust for illumination variations [7,8]. In [3], the LBP encoded images were directly used in the linear SRC system. However, since LBP codes are converted

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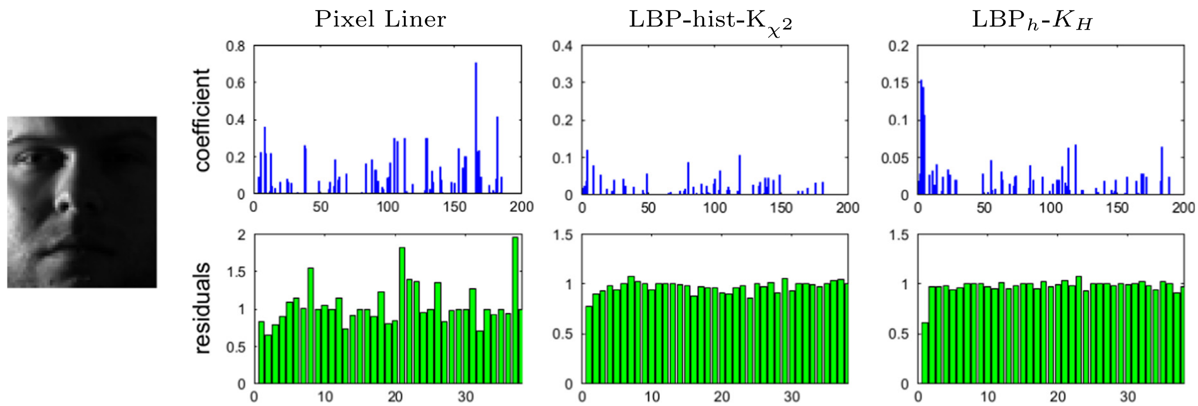

Fig. 1. Sparse codings (blue bars) and residuals (green bars) by three kernel methods in representing a probe face image (left) in terms of a gallery of 38 subjects (5 images per subject) from the Extended YaleB database. Pixel Linear denotes the linear SRC method with raw image pixels as features. LBP-Hist-K_{χ^2} denotes kernel SRC with LBP histogram based χ^2 kernel. LBP$_h$-K_H denotes kernel SRC with the proposed LBP binary string and Hamming distance based kernel. The first five images in the gallery have the same identity with the probe image. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

from binary comparisons, i.e. they are labels but not regular numerical values, thus it is not very reasonable to linearly combine LBP values directly. Actually, LBP is mostly used in the form of histogram features counted in local regions, and the χ^2 distance is preferred to calculate distance between two LBP histogram features [6,7]. Different from [3], Chan and Kittler [5] proposed to extract LBP histogram features instead of single label for linear SRC based face recognition. However, in all these studies, LBP histogram features have only been integrated in the linear SRC algorithm, which is not able to further discover nonlinear relationships between probe and gallery images via useful nonlinear kernels, such as the histogram intersection and χ^2 kernels. Therefore, in this paper, we propose a kernel SRC based algorithm to effectively integrate nonlinear features in nonlinear kernels for face recognition. In the examples of Fig. 1, it shows that kernel SRC with the LBP histogram based χ^2 kernel can deal with illumination variations better than the linear SRC method.

Since LBP is originally a binary string, in this paper, we further develop an effective local image feature and Hamming distance based kernel (LBP$_h$-K_H), for better utilizing the advantages of LBP features. Note that while the LBP histogram based kernels work in the region-level, LBP$_h$-K_H is a pixel-level kernel which can represent local image details better. In Fig. 1 it can be observed that the proposed LBP$_h$-K_H is better than LBP in representing the probe face having severe illumination changes. The success is because with the proposed nonlinear kernel, the relationship between the probe image and the gallery images of the same class can be better discovered.

Therefore, in this work, we propose a novel kernel SRC framework, and apply it together with local image descriptors to face recognition. The contributions can be highlighted as follows:

1. We propose a novel kernel coordinate descent (KCD) algorithm with covariant update technique for the kernel LASSO problem.
2. The KCD algorithm is further applied to face recognition in the SRC framework (KCD-SRC), which enables many effective similarity kernels to be used in the SRC framework for face recognition.
3. We integrate the well-known LBP features into the proposed KCD-SRC framework, where both χ^2 distance based and histogram intersection (*HI*) based kernels can be successfully applied for effective face recognition.
4. Furthermore, we propose a new pixel-level kernel for the LBP feature, denoted as LBP$_h$-K_H, to the KCD-SRC based face recognition. We show that this simple kernel is fast and robust for face recognition under occlusion and illumination variations.

We have conducted extensive experiments on the Extended YaleB, CMU-PIE and the AR face databases to illustrate the effectiveness of the proposed approach in four scenarios, including illumination variations, noise corruptions, occlusions, and registration errors. The results demonstrate that the kernel enabled methods are more effective and robust than methods without kernel. For example, in many situations, KCD-SRC with LBP$_h$-K_H outperforms the raw pixel based SRC method with more than 20% recognition rates under only five training samples per subject.

This work is based on our preliminary work in [9]. The main improvement is the development of the LBP$_h$-K_H kernel, which utilizes only one half of the LBP encodings. We demonstrate that LBP$_h$-K_H is equivalent to the K_H kernel that we have proposed in [9], but reduces one-half of the computation. It is also equivalent to the linear kernel by a modification to the LBP encoding, but LBP$_h$-K_H is more efficient. It is impressive that while the computation time of LBP$_h$-K_H based KCD-SRC method is comparable to that of raw pixels based, the former performs much better. Other main changes contained in this paper include

1. We give a more detailed formulation of the proposed KCD-SRC algorithm.
2. The *HI* kernel is evaluated in addition to the χ^2 kernel for LBP histogram based KCD-SRC algorithm.
3. The AR database is included for evaluation in real occlusion scenarios (with sunglasses and scarf).
4. Extended experiments are performed on the CMU-PIE database with various scenarios.
5. A more challenging scenario, misalignment, is evaluated to test the proposed methods for face recognition, including both synthesized and real registration errors.

1.1. Related work

The kernel LASSO problem (Eq. (1)) has also been suggested by Yuan and Yan [3] and Gao et al. [10]. In the work of Yuan et al. [3], the formulation is addressed in a multi-task learning setting, and the resulted optimization problem is solved via the accelerated proximal gradient method [11]. Differently, our formulation does not need to combine multiple features in face recognition. The LBP descriptor is also utilized in their work. However, they combined the gray-level images and LBP encoded images directly to represent each face image, which resulted in a two-task classification problem using sparse representation. As mentioned before, directly operating on LBP labels in a numerical way lacks of physical meanings. In contrast, we suggest applying LBP histograms extracted from local regions for our kernel formulation. In addition, we propose a new LBP$_h$-K_H kernel, which