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# Similar handwritten Chinese character recognition by kernel discriminative locality alignment

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A B S T R A C T

It is essential to extract the discriminative information for similar handwritten Chinese character recognition (SHCCR) that plays a key role to improve the performance of handwritten Chinese character recognition. This paper first introduces a new manifold learning based subspace learning algorithm, discriminative locality alignment (DLA), to SHCCR. Afterward, we propose the kernel version of DLA, kernel discriminative locality alignment (KDLA), and carefully prove that learning KDLA is equal to conducting kernel principal component analysis (KPCA) followed by DLA. This theoretical investigation can be utilized to better understand KDLA, i.e., the subspace spanned by KDLA is essentially the subspace spanned by DLA on the principal components of KPCA. Experimental results demonstrate that DLA and KDLA are more effective than representative discriminative information extraction algorithms in terms of recognition accuracy.



## 1. Introduction

In recent years, handwritten Chinese character recognition (HCCR) has made great progress in both research and practical applications. Unconstrained online HCCR, however, is still an open problem remaining to be solved, because it is still challenging to reach high recognition rate considering the high diversity of handwriting styles and large category set (Gao and Liu, 2008; Leung and Leung, 2010; Liu et al., 2010; Shao et al., 2011). In constrained HCCR, recognition rate can generally reach to over 98.5%; but in unconstrained online HCCR, the recognition rate drops to 92.39% (Liu et al., 2010).

Many effective methods have been proposed to promote the recognition rate in cursive online or offline HCCR. Gao and Liu (2008) presented a linear discriminant analysis (LDA)-based compound distance method to boost the recognition rate. Leung and Leung (2010) presented critical region analysis, which can distinguish one character from another similar character by emphasizing the critical regions. All of the methods above are concerned with constructing a globally linear transformation to improve recognition accuracy.

In fact, one of the main reasons for the performance drop in unconstrained online HCCR lies in that similar Chinese character often share an analogous structure, and have only presence or absence of a stroke in a specific region. Fig. 1 shows some similar cursive samples from the CASIA-OLHWD1 database (Wang et al., 2009). There is usually only one classifier for all classes in many HCCR systems. Systems of this sort are easy to construct, but fail to distinguish very similar Chinese characters.

Therefore many Chinese character recognition engines (Leung and Leung, 2010) adopt a hierarchical classifier to overcome the shortage of a single classifier. When a newly imported character is identified by the first-level, the recognition results can be reordered by the confidence score in general. The second-level classifier aims to distinguish the top confidence score results. Many methods (Gao and Liu, 2008; Shao et al., 2011; Leung and Leung, 2010) have been presented to identity the small subsets of Chinese characters. These methods aim to effectively extract the discriminative information of the simplest circumstance, i.e., a pair of similar Chinese character classes.

Although the recognition rate can be boosted, there is still room to obtain further improvement. First, using pairwise classifiers to reorder the candidate character in second-level classification task is an expensive approach, because the number of classifiers is $C(C-1)/2$ for a $C$-class classification problem. The time cost and space cost of this strategy is not accepted easily in general. Second, discriminative information extraction is considerably important in similar handwritten Chinese character recognition (SHCCR). We thus apply the DLA (discriminative locality alignment) manifold learning (Shao et al., 2011) and static candidate generation technique (Liu and Jin, 2007) to address these issues. Fig. 2 shows the diagram of the proposed recognition system. At the first level classification, the similar Chinese candidate sets for each class is generated using the static candidate generation technique

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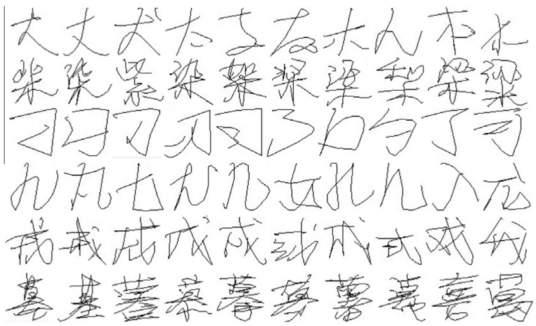

**Fig. 1.** Similar samples in handwritten Chinese character from CASIA-OLHWD1 database.

(Liu and Jin, 2007). Then when the first candidate is given by the first level classification, the system retrieves the corresponding similar Chinese candidate set according to the first candidate on which the second level classification is carried. DLA or kernel DLA (KDLA, which is proposed in this paper) projection matrix is applied in the selected similar character set on the consideration to improve the recognition accuracy by learning more effective discriminative features in the similar candidate set.

Linear discriminant analysis (LDA) (Fisher, 1936) is one of the widely used similar Chinese characters discriminative feature extraction methods in the literature (Gao and Liu, 2008; Jin et al., 2010; Leung and Leung, 2010; Shao et al., 2011). Traditional LDA, however, suffers from the following drawbacks. First, it ignores the local structure of samples, which makes it fail to discover the nonlinear structure hidden in the high dimensional space. Second, LDA is confronted with the small sample size (SSS) problem (Bian, 2011; Tao et al., 2009; Tao et al., 2007). We need a large number of samples for model training.

Manifold learning based dimension reduction algorithms are the powerful tools for finding the intrinsic structure of a set of samples embedded in a high dimensional ambient space and attracted intensive attention in recent years (Belkin and Niyogi, 2002; Bengio et al., 2004; Cai et al., 2005; Guan, 2012; Guan, 2012; He and Niyogi, 2004; Si, 2010; Tian, 2012; Wang, 2011; Zhou, 2011). Therefore, to overcome the above problems of LDA for performance improvement, we introduce a popular supervised manifold learning approach to SHCCR, which is called discriminative locality alignment (DLA) (Zhang et al., 2008). DLA is developed under the umbrella of patch alignment framework (PAF) (Guan, 2011; Zhang et al., 2009). PAF includes most existing manifold learning based dimension reduction algorithms as special cases and shows that these algorithms can be divided into two steps: patch optimization and global alignment. Based on PAF, we can easily understand the common points and essential differences of different algorithms, and develop new manifold learning based dimension reduction algorithms. DLA is a special implementation of PAF for classification. It contains two stages. In the first stage, DLA preserves the discriminative information in a local patch through integrating two criteria that the distances between the intra-class samples will be as small as possible and the distance between the inter-class samples will be as large as possible. In the second stage, DLA integrates all the weighted part optimizations to form a global subspace structure through an alignment operation.

As a manifold learning based method, DLA has many attractive properties for SHCCR compared to LDA. First, DLA focuses on local discriminative structure for each training sample, and it captures the discriminative information at the sample level, and thus it is more powerful than LDA. Second, DLA obtains robust classification performance under the condition of small sample size. Third, it does not need to compute the inverse of a matrix, and thus it does not face the matrix singularity problem. In addition, our experimental results show that a smaller size projection matrix obtained by DLA compared with that obtained by LDA can achieve a high recognition rate for SHCCR. That means DLA is able to keep a higher recognition rate with less computing and storage costs, which is attractive for practical applications.

However DLA is a linear algorithm, which cannot capture the nonlinearity of the samples. Motivated by kernel methods (Geng, 2011; Muller et al., 2001) successfully used for discovering the intrinsic nonlinear structure, we generalize DLA to the kernel feature space as the Kernel discriminative locality alignment (KDLA). According to the so-called "kernel trick", we map the original low-dimensional input Euclidean space to a high-dimensional Hilbert space, in which samples from different classes are almost linearly separable. KDLA obtains a set of optimal discriminative basis vectors in the high-dimensional Hilbert space. Therefore, KDLA performs much better than DLA. We prove that learning KDLA is equivalent to learning DLA in the space spanned by principal components of kernel principle component analysis (KPCA)

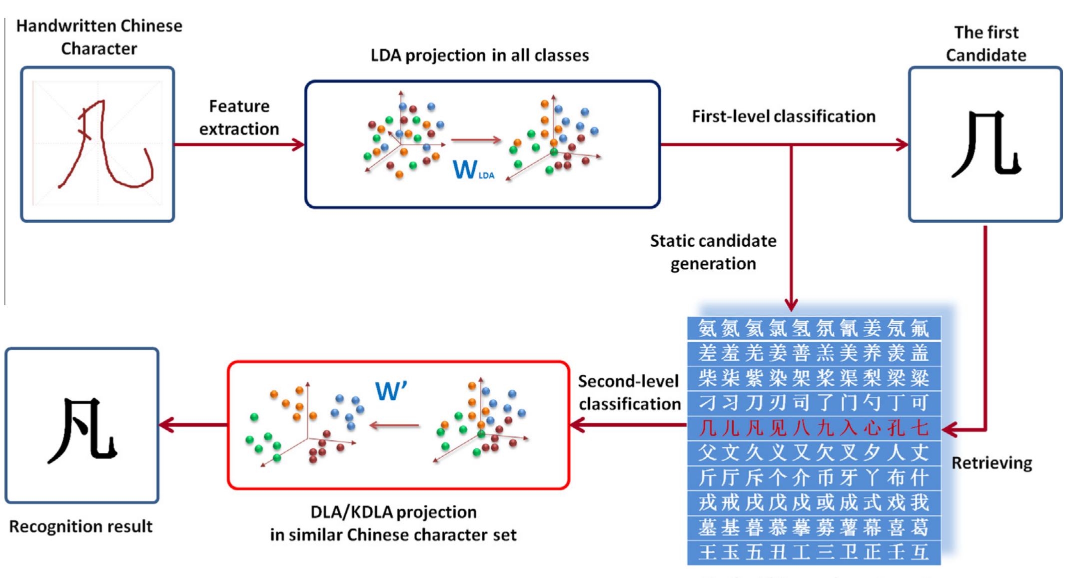


**Fig. 2.** The static candidate generation technique based SHCCR system.